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A Thesis

by

VICTOR CARAVELLO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 1998

Major Subject: Toxicology

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August 1998

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EVALUATION OF THE EFFECTIVENESS OF USING ALFALFA AND BUFFALO GRASS FOR REMEDIATION OF TRICHLOROETHYLENE FROM GROUNDWATER

Victor Caravello, Captain, USAF, BSC, 1998
101 pages, Master of Science, Texas A&M University

Phytoremediation is receiving increasing attention due to the potential for vegetation to play a significant role in bioremediation of contaminated soils and groundwater. The purpose of this research was to conduct a pilot study to determine if buffalo grass would enhance the remediation of groundwater contaminated with trichloroethylene (TCE). A mass-balance experiment was designed and executed to determine the extent of TCE remediation/degradation occurring through buffalo grass. Measurements for TCE in air, water, and soil were completed for three treatments: buffalo grass, alfalfa, and soil. In total, 267 air samples, 43 water samples, 85 soil samples, and 40 vegetative samples were collected and analyzed. The analysis identified two important facts. First, there were no significant differences detected between TCE concentrations in soil, water, and air between groups. Second, there is a significant difference in the amount of the TCE-water mixture consumed in chambers with plants versus chambers without plants. The mass balance of our experiment was not achieved due to unaccountable losses of TCE from the chambers. The major loss mechanism for TCE appears to be from the breakthrough of air sampling media during the experiment. Thus, the data are insufficient to determine if remediation occurred via plants or by preferential pathways through the soil. Future experiments should be designed to include daily monitoring of the aquifer, humidity tolerant air sampling protocol, and relief from the build-up of humidity and transpiration inside the chambers.

ABSTRACT

Evaluation of the Effectiveness of Using Alfalfa and Buffalo Grass

for Remediation of Trichloroethylene from Groundwater. (August 1998)

Victor Caravello, B. S., Binghamton University

Co-Chairs of Advisory Committee: Dr. K. S. Ramos
Dr. J. C. Rock

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INTRODUCTION

Background

Groundwater contamination with halogenated solvents is a pervasive problem across much of the United States. The groundwater under Carswell Air Force Base (AFB), located in Fort Worth, Texas, is contaminated with trichloroethylene (TCE). Various concentrations of TCE have been detected within the aquifer with a peak at 800 parts per billion (ppb). The leadership at Carswell AFB is seeking alternative measures for remediating the aquifer to preclude inadvertent exposures to the surrounding communities as well as the base population. Phytoremediation was chosen as the primary technique for further investigation.

The Carswell AFB Leadership selected buffalo grass as the plant to be tested for a number of reasons. First, buffalo grass is native to the region and therefore would thrive in the North Texas climate. Second, the height of the blades does not exceed 10 inches and therefore, the frequency of mowing areas where buffalo grass is planted can be reduced. Lastly, buffalo grass is known to have roots as deep as 10 feet, which would enhance the uptake of contaminated water (1).

The depth to ground water at Carswell AFB ranges from 5 to 30 feet with an average of 19 feet. Based on a TCE plume map for Carswell AFB, the TCE concentration at the shallow groundwater depth ranges from 50-100 ppb (2).

This thesis follows the style and format of *Environmental Science & Technology*.

The Departments of Nuclear Engineering, Veterinary Anatomy and Public Health, and Veterinary Physiology and Pharmacology at Texas A&M University agreed to investigate the plausibility of using Buffalo grass to remediate TCE from ground water. A pilot study was designed to optimize environmental conditions to determine if buffalo grass will uptake TCE.

Buffalo Grass

Buffalo grass (*Buchloe dactyloides*) commonly grows to a height of 8 to 10 inches. Individual leaf blade length can easily exceed 10 inches, but they fall over and give the turf a short appearance. It is a warm season perennial grass that is native from the Great Plains of Montana to Mexico. In Texas, it is commonly found from South Texas to the Texas Panhandle, but is rarely found on the sandy soils of the eastern part of the state or the high rainfall areas of the southeast. Buffalo grass is one of the grasses that supported the herds of buffalo that roamed the Great Plains and provided the sod that the early settlers used to build their homes (3).

Buffalo grass is a native turf grass from which many other varieties of turf grasses have been developed. Its tolerance to prolonged droughts and to extreme temperatures, together with its seed producing characteristics enables buffalo grass to survive extreme environmental conditions (3, 4). When irrigated and fertilized, buffalo grass is easily invaded by Bermuda grass (3). On average, its warm season evapotranspiration rate is 0.21 – 0.29 inches per day, which is affected by light duration and intensity, temperature, wind, soil moisture tension and water usage rate

(5). The water usage rate is greatest under clear, windy conditions with high temperature and low humidity.

Trichloroethylene

Trichloroethylene ($ClHC=CCl_2$) is a colorless liquid at room temperature with an odor similar to ether or chloroform. It is a man-made chemical that does not occur naturally in the environment. TCE is an industrial solvent used for vapor degreasing and cold cleaning of fabricated metal parts (6). In the past, TCE has also been used as a carrier solvent for the active ingredients of insecticides and fungicides, as a solvent for waxes, fats, resins, and oils, as an anesthetic for medical and dental use, and as an extractant for spice oleoresins and for caffeine from coffee (7). Trichloroethylene was also found in printing inks, varnishes, adhesives, paints, lacquers, spot removers, rug cleaners, disinfectants, and cosmetic cleansing fluids. TCE may also be used as a chain terminator in polyvinyl chloride production and as an intermediate in the production of pentachloroethane. Trichloroethylene is no longer used with foods, drugs, or cosmetics (8). In many cases, as much as 94% of TCE used in degreasing operations was released to the environment (6). The widespread use of TCE as a solvent and its subsequent disposal has resulted in extensive contamination of groundwater. Trichloroethylene has been detected in at least 852 of the 1,430 hazardous waste sites on the National Priorities List (NPL) sites identified by the U.S. Environmental Protection Agency (EPA)(9).

The two main sources of human exposure to trichloroethylene are the environment and the workplace. Background levels of trichloroethylene can be found in the outdoor air we breathe (30 to 460 parts per trillion) and in many lakes, streams, and underground water used as sources of drinking water for homes and businesses. Various federal and state surveys indicate that between 9 and 34% of the water supply sources in the United States may be contaminated with trichloroethylene (9). Contaminated water supplies typically contain 1 to 2 parts per billion and the solubility of TCE in water is 1 mg/mL at 4°C. Currently, the EPA has established the maximum contaminant level (MCL) for TCE in drinking water at 5 ppb (10). Another important source of environmental release of trichloroethylene is evaporation to the atmosphere from work done to remove grease from metal. In addition, at locations where wastes are disposed, trichloroethylene is released to the air by evaporation from a source and by diffusion through soil from underground water (11). In sites that are heavily contaminated with TCE, spills accumulate as pools of non-aqueous phase liquid slowly dissolving into the groundwater and providing a persistent source of contamination.

A major concern associated with the presence of TCE in drinking water is the potential for adverse health effects in an exposed population. Exposure to TCE through ingestion or inhalation results in almost complete absorption of the chemical, while reduced amounts of TCE penetrate via dermal absorption. At low doses, approximately 70-90% of an absorbed dose is metabolized in the liver, while approximately 10-20% of inhaled TCE is excreted as unchanged trichloroethylene.

Following workplace exposures between 100 and 200 ppm TCE, approximately 30-50% of an absorbed dose appears in the urine as trichloroethanol and 10-30% as trichloroacetic acid (6). Short term adverse effects observed in populations that ingested TCE in their drinking water at levels above the MCL includes vomiting and abdominal pain, whereas lifetime exposure to TCE above the MCL has the potential to cause liver damage and cancer (10). Although the Carswell AFB aquifer is not used for drinking water, it discharges into Lake Fort Worth, which is used as a source of drinking water. Currently, the plume of TCE under Carswell AFB has not reached the base boundaries and is not entering Lake Forth Worth.

Phytoremediation

In the United States, the cost of remediating Superfund and Resource Conservation and Recovery Act (RCRA) sites is estimated at $750 billion (12). These high costs encourage companies to seek alternative methods of treating contaminated sites. Phytoremediation may be a big part of the answer to this problem. Phytoremediation is the use of plants, grasses and trees to remove, degrade or immobilize hazardous contaminants from the environment. It is rapidly gaining acceptance in the site remediation industry. This technology is potentially applicable to a variety of contaminants, including heavy metals, radionuclides, inorganic compounds and organic compounds, and can be used on soils, groundwater and wastewater. Generally it is limited to shallow soils, streams, and ground water. Other limitations to phytoremediation include: 1) high concentrations of hazardous materials

can be toxic to plants; 2) phytoremediation involves the same mass transfer limitations as other biotreatments; 3) climatic or seasonal conditions may interfere or inhibit plant growth, slow remediation efforts, or increase the length of the treatment period; 4) phytoremediation can transfer contamination across media (e.g., from soil to air); 5) phytoremediation is not effective for strongly sorbed (e.g., PCBs) and weakly sorbed contaminants; 6) phytoremediation will likely require a large surface area of land for remediation; 7) the toxicity and bioavailability of biodegradation products are not always known (13).

Vegetation may enhance biodegradation by accumulating, metabolizing, or volatizing a contaminant (14). Preliminary investigations have shown the effects of phytoremediation ranging from enhancing biodegradation (15), to having no effect, or even negative impact (14). An investigation at Hill AFB located in Salt Lake City, Utah has shown that TCE is not likely to be transmitted through the vegetative food chain, but can be actively broken down by plants in the legume family (16). Phytodegradation is the metabolism of contaminants within plant tissues. Plants produce enzymes, such as dehalogenase and oxygenase, which help catalyze degradation. Pollutants are degraded into simpler molecules and used to help the plant grow faster. Plants contain enzymes, a broad category of chemical substances that cause rapid chemical reactions to occur. Enzymes in plant roots degrade organic contaminants. The fragments are incorporated into new plant material. Enhanced rhizosphere biodegradation takes place in the rhizosphere (root zone of the plants) and is a much slower process than phytodegradation. Phytovolatilization occurs as plants

take up water containing organic contaminants and release the contaminants into the air through their leaves. Plants can also break down organic contaminants and release breakdown products into air through leaves. A good example of phytovolatilization is growing trees and other plants take up water and the organic contaminants in it. Depending on the type of trees, climate, and season, trees can act as organic pumps when their roots reach down toward the water table and establish a dense root mass that takes up large quantities of water. Some of these contaminants can pass through the plants to the leaves and evaporate. Poplar trees, for example, can volatilize 90% of the TCE taken-up (13, 16, 17).

Phytoremediation is receiving increasing attention due to awareness of the significant role vegetation may play in bioremediating contaminated soils and groundwater. Even with increased attention focused on plant-based bioremediation, research studies to identify the role of vegetation in the bioremediation of chlorinated compounds are limited (18). Research is still needed to establish whether contaminants can collect in the leaves and wood of trees used for phytoremediation and be released when the leaves fall in the autumn or when firewood or mulch from the trees is used (16). Products may be mobilized into ground water or bioaccumulated in animals. Further research is needed to study the effects on the food chain that could occur if insects and small rodents eat the plants that are storing contaminants and are then eaten by larger mammals. More research is needed to determine the fate of various compounds in the plant metabolic cycle to ensure that plant droppings and products manufactured by plants do not contribute toxic or

harmful chemicals into the food chain or increase risk exposure to the general public (18).

Obviously, there is much needed work in this new field and there are several very sensible reasons to increase the level of research in the phytoremediation. First, less energy--plants use solar energy and evapotranspiration may be considered a solar powered pump-and-treat system that helps bring contaminants to the rhizosphere for bioremediation and containment. Second, public acceptance--plants are typically more aesthetically pleasing than a bioreactor, air-stripping unit, or other mechanized remediation technique. Third, survivability and uptake potential--since plants are commonly present at contamination sites, a basic understanding of how they interact with contaminants is important. Forth, cost-savings--vegetation can be managed relatively inexpensively and efficiently to produce biomass for chemical or energy applications (14).

Previous Success

The successful remediation of TCE from ground water has been demonstrated in numerous investigations other than phytoremediation. Successful remediation methods for TCE include pump-and-treat and in-situ bioremediation. Pump-and-treat is the industry and regulatory standard for remediating groundwater contaminated with volatile organic compounds. In spite of its wide acceptance, this method is both ineffective and expensive. The startup capital cost is typically more than $1 million and the annual operating cost is approximately $300 thousand (19). This type of

treatment normally requires a 20-30 year operation to reduce the aquifer contamination within the regulatory requirements. A brief description of selected pump-and-treat systems is provided in Appendix A.

In-situ bioremediation of TCE is an attractive alternative to pump-and-treat. It degrades the contaminant without bringing it to the surface. One of the major problems with in-situ bioremediation of TCE is the co-metabolic nature of the degradation process; mircoorganisms do not derive carbon or energy from reaction with TCE, so a bacterial population must be externally supplied. Co-metabolic degradation is a process through which microbes that derive energy and growth by degrading a primary substrate can concomitantly degrade other substrates such as TCE (18, 20). Microorganisms (yeast, fungi, or bacteria) consume and digest organic substances for nutrition and energy. Certain microorganisms can digest organic substances such as fuels or solvents that are hazardous to humans and break them down into harmless products in a process called biodegradation. Natural substances released by the plant roots—sugars, alcohols, and acids—contain organic carbon that provides food for soil microorganisms and the additional nutrients enhance their activity (16). Biodegradation is also aided by the way plants loosen the soil and transport water to the area.

In a study conducted at Stanford University, the effectiveness of TCE co-metabolism by an indigenous phenol-fed microbial population declined significantly over a 280-day experiment. The decline in degradation has not been seen in shorter experiments and it leads to the formation of toxic products. The data from this

experiment suggests that the addition of microorganisms with the phenol led to the depletion of dissolved oxygen. After the bioaugmentation was no longer fed to the mircocosms, dissolved oxygen levels recovered in all microcosms and those microcosms that continued to receive phenol returned to or surpassed previous TCE transformation levels (21). There are two lessons to learn from this study, first, co-metabolism degradation of TCE requires a delicate balance of nutrients, target substrates, and dissolved oxygen, and second, initial success with biodegradation does not guarantee long term success. Phytoremediation projects will often be carried out over years.

Phytoremediation has been successfully tested in many locations. Research conducted at Kansas State University tracked the degradation of trichloroethane (TCA) and trichloroethylene (TCE) in a laboratory chamber with alfalfa plants. Biodegradation of TCE under aerobic conditions occurred through a co-metabolic mechanism. Gas-phase monitoring of TCE in the headspace of the chamber was conducted using FT-IR measurements and found that the TCE accumulated at 2 ppm/hr. In subsequent work, TCE was fed into the chamber and the results were similar with and without alfalfa plants. No controls were conducted with that experiment (22). The data suggests that alfalfa had minimum impact on the remediation process whereas the microbes did a fair job of degrading TCE into innocuous substrates.

Generally, the use of phytoremediation is limited to sites with lower contaminant concentrations and contamination in shallow soils, streams, and ground

water. However, researchers are finding that the use of trees (rather than smaller plants) allows them to treat deeper contamination because tree roots penetrate more deeply into the ground. Trees can act as organic pumps when their roots reach down toward the water table and establish a dense root mass that takes up large quantities of water. Poplar trees, for example, pull 30 gallons of water out of the ground per day, and cottonwoods can transpire up to 350 gallons per day (13). A comparison of water transpired from cottonwoods and buffalo grass was conducted showing that transpiration for cottonwood trees is 0.389 gallons/square foot/day and is based on a 30' planting distance between trees and a rate of 350 gallons/day/tree. The calculated result for buffalo grass is 0.156 gallons/square foot/day and is based on 0.25"/day.

Researchers at the University of Washington are exploring the use of hybrid poplar trees that have the ability to remove and degrade trichloroethylene (TCE) and certain other chlorinated organic solvents from soil and water. This poplar hybrid grows at a remarkable rate--up to 10-15 feet per year. Initial laboratory studies indicate the trees are capable of metabolizing TCE to innocuous products (23). A similar effort is being conducted at Carswell AFB where eastern cottonwood trees were planted above a dissolved TCE plume in a shallow alluvial aquifer. The trees are expected to act as a natural pump-and-treat system.

In Iowa, the EPA demonstrated the usage of phytoremediation by planting poplar trees along a stream bank between a cornfield and the stream. These trees acted as natural pumps to keep toxic herbicides, pesticides, and fertilizers out of the streams and ground water. After three years, while the nitrate concentration in ground water at

the edge of the cornfield was measured at 150 mg/L, the ground water among the poplar trees along the stream bank had nitrate concentration of only 3 mg/L (17).

Objectives

The primary objective of this thesis project was to test the null hypothesis that buffalo grass would not enhance the remediation of groundwater contaminated with trichloroethylene (TCE). To achieve this, three specific objectives were established. First, develop a mass balance experiment to capture TCE and its byproducts. Second, monitor each chamber to quantify the input of TCE and the output of TCE and all breakdown products. Third, assess the change in health risk based on the successful remediation of the groundwater.

MATERIALS AND METHODS

This project was conducted in four phases. Planning the experiment and the initial equipment fabrication started in phase I. During phase II, the buffalo grass was grown in polyvinyl chloride (PVC) columns to establish a 12-inch root structure and custom glass growth chambers were fabricated. Phase III involved transferring the test columns into experimental glass chambers and introducing the TCE into the appropriate chambers. The final phase, phase IV, involved data collection, analysis, and reporting. Each phase is described in detail below.

Phase I (Planning/Equipment Fabrication)

By virtue of the ambitious schedule of this project, the planning phase of this research continued through Phase III. The immediate concern was finding a source of native buffalo grass and getting the project underway. For purposes of statistical power and design, the number of test chambers was maximized for the allocated budget to enhance the probability of obtaining statistically meaningful data. The project was designed to utilize 24 experimental test chambers. Statistical power calculations were not conducted until the termination of the experiment because the natural variability in the treatment population was not known.

Environmental conditions were optimized by using a greenhouse, distilled water, artificial heat and lighting, and nutrients. Other environmental fluxes were uncontrolled. These include temperature variations in root structure (temperature at

the surface vs. temperature at 6-12 inches down), ground water temperature, and rainfall.

The equipment requirements to conduct the experiment were identified during this phase, but the procurement was completed on the just-in-time basis. Some of the basic items included a green house, lighting with the correct solar spectrum, grass growth columns, drainage for the columns, distilled water, monitoring equipment, nutrients, experimental test chambers, sample collection media, and a timer.

A 1000-watt super metal halide (high-intensity discharge) lighting system was purchased from Home Harvest located in Reston, Virginia. The system used an Agrosun halide bulb that provided a full spectrum and color corrected output at a 117 thousand foot-candle rating. The Agrosun bulb provides the normal blue light for growth and an additional red light to maximize flowering and fruiting. At the beginning of the fall 1997, the lighting system was put into operation on a cycle of 16 hours a day.

Once the experimental test chamber design was finalized, it was ordered through the Custom Glass Shop, a Division of Kontes Glass Company located in Vineland, NJ. The glass test chambers were annealed and finished with tooled flanged ends. The chambers consisted of a bottom and a top piece with an outside diameter of 110 millimeters (mm), a wall thickness of 2.5 mm, and tooled flanged ends with grounded surfaces. The bottom is 550 cm tall and has a stopcock approximately 50 mm from the bottom of the unit. The top piece is 450 mm tall and has two 0.25-inch openings at the top. A schematic view is shown in Figure 1.

Buffalo grass tends to respond well to light applications of nitrogen. Schultz Acid Plus Plant Food was selected based on its 33% nitrogen content. It was added to distilled water at a rate of ½ teaspoon per gallon prior to watering the plants.

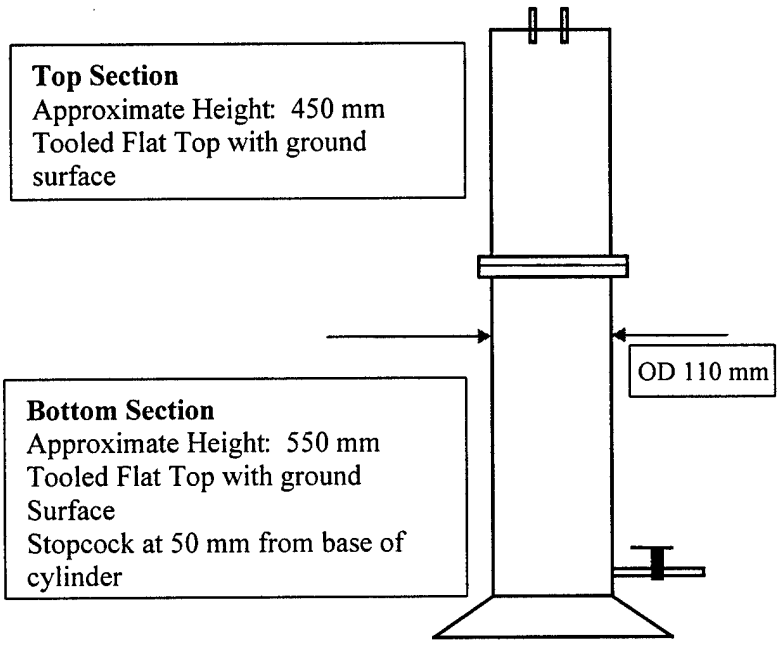

FIGURE 1. Schematic View of Experimental Test Chamber.
OD = outside diameter.

Phase II (Establishment of Buffalo Grass)

In total, 32 PVC columns were prepared for this project. The PVC columns measured 15 inches in height with a 4-inch inside diameter. Each column contained categorized soil that was transferred to an experimental glass test chamber prior to the introduction of TCE in Phase III. The soil used in this study was a Norwood

(Weswood) soil donated by Dr. K. C. Donnelly. The Norwood profile was reasonably uniform and selected to typify the range of textures and other characteristics for growing plants. The following analysis is based on a previous report of the same soil characteristics (24).

All analyses were carried out according to standard procedures. The texture was measured on samples dispersed with a milk shake mixer in a solution of sodium pyrophosphate 10 hydrate. The density of the suspension was measured at appropriate times with a Bouyoucos hydrometer. Appropriate temperature corrections were made. The United States Department of Agriculture (USDA) classification was used. The bulk density was calculated as the dry weight per unit volume. The water contents were determined in the same cores and expressed as percent by volume. A series of moisture potentials including saturation, field capacity, wilting point and oven dry were utilized. The height and diameter of the soil core at each potential were utilized to determine the bulk density. Cation exchange capacity was determined by replacing all the cations with NH4 then measuring the evolved NH3. Schollenberger and Simon (1945) describe the technique. The results are expressed in milliequivalents per 100 g of soil dried to 105°C. The percent carbon was determined by a wet oxidation technique. A 1:1 weight ratio of soil to water was prepared for pH determinations using a standard pH meter (24).

Soil characterization data were used to determine the potential for sustaining plant and microbe life by evaluating the nutrients present. Soil characterization data are provided in Table 1. The experiment involved 12 experimental test chambers used

for buffalo grass, 6 chambers for alfalfa, and 6 chambers for soil without plants. An overview of the pH column requirements by type is shown in Figure 2.

TABLE 1. Soil Characterization Data.

Depth (inches)	Sand (%)	Silt (%)	Clay (%)	pH	Texture
0-6	48.2	15.2	36.6	7.69	Sandy clay
6-12	49.6	15.1	35.3	7.73	Sandy clay loam

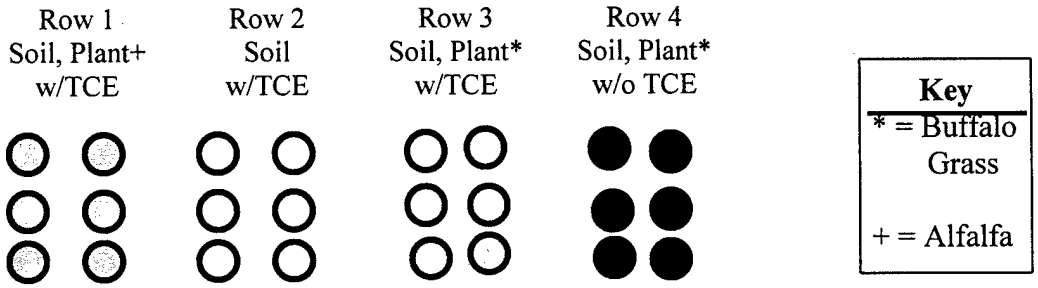

FIGURE 2. Column Requirements by Type. The experimental design called for TCE to be added in rows 1, 2, and 3. Row 2 was used as a control to compare TCE recovery between the rows with plants (1 and 3). Row 4 is a control for row 3; if plants in row 3 die and row 4 plants are healthy, then TCE can be suspected for causing plant death. Amount of TCE added was proportional to water added (1 μL/100mL)

The buffalo grass chosen for this experiment is a native prairie type of Texoka supplied by Texas A&M University Crop and Science Field Laboratory. The buffalo grass used was grown from sod and was obtained courtesy of Dr. R. White. The sod was cut from a plot maintained by the Crop and Science Field Laboratory. To

eliminate outside sources of contamination, the sod was cleaned with a garden hose to remove all debris (soil, rocks, insects, etc.) and the roots were cut. These procedures, as well as the transplant process, can result in plant stress and inhibition of growth. For the first week following the transplanting, the buffalo grass did not recover. During the second week, an ultraviolet radiation (UV) cover on the greenhouse was rolled back and the watering frequency was reduced. The buffalo grass then started to respond favorably. To increase the probability of achieving good plant growth, 20 PVC columns were used to grow buffalo grass. Alfalfa plants were grown from seed in 6 columns.

With the plant columns, the goal was to achieve a deep root structure (12-15 inches) as soon as possible in order to progress to the phytoremediation phase. To minimize the variations between the types of columns, the soil columns were given the same nutrient load as the plant columns. Once buffalo grass was transplanted, a 12-inch root structure was in place within 6 weeks.

Once the roots were developed in the PVC columns, the columns were maintained until they were transplanted to a glass experimental test chamber. The test chambers contained three distinct zones: a gravel zone, a sand zone, and a soil zone. The gravel and sand zones represented an aquifer. All columns/chambers had the same type of soil, sand, and gravel.

Prior to initiation of Phase III, buffalo grass and alfalfa plants were stress-tested to determine if and how they were affected as TCE was introduced into the root zone. Three concentrations (1 ppm, 10 ppm, and 100 ppm) were administered to

increase confidence that the applied concentration of TCE used in Phase III (20 ppm) does not induce the death of the buffalo grass and alfalfa in the experimental test chambers. The term ppm used here refers to a proportion of TCE to water with the units being μL TCE to L of water. Our stress tests of alfalfa and buffalo grass were conducted over a 2-week period and no effect was observed. Research with TCE being mixed with water and administered to alfalfa plants at the University of Kansas resulted in no pathology at 50 ppm (21). No effect occurred in our stress test at 100 ppm, so the no observed effect level (NOEL) was concluded to be at least 100 ppm for both buffalo grass and alfalfa. At the end of the stress tests, laboratory analysis was performed on the various grasses to determine if TCE was present and detectable.

The plant material was analyzed on campus in Dr. Beverly Clement's Laboratory using tetradecane to extract the TCE. The cut grass was weighed and combined with a proportionate ratio of tetradecane in a blender. The mixture was blended for approximately 2 minutes and the extract from the mix was injected into a Hewlett Packard (HP) gas chromatograph mass spectrograph (GC/MS), model 5970B, for analysis. The samples were manually injected and analyzed based on mass peak values. Along with the mass peak values, the corresponding ion peaks were also checked for appropriate proportion. No definitive data were obtained from the grass samples suggesting that TCE was not present at detectable quantities or alternatively, not recovered from the grass during this procedure.

Phase III (Introduction of TCE)

At the conclusion of the stress test, plants were transferred to experimental test chambers. Once all of the columns were transferred to experimental test chambers, the chambers were sealed at night using sealant and brackets to hold the chambers in place. All 6 alfalfa chambers and 3 of the 6 soil chambers were sealed and 12 hour air samples were collected the next morning. The remaining soil and 12 buffalo grass chambers were sealed the following night. The chambers were sealed with Permatex Hylomar HPF gasket sealant. The gasket sealant is a high performance formulation (HPF) that does not contain ozone depleting or volatile organic compounds (ODC/VOC). It does contain special high temperature additives that allow it to remain pliable with high tack/adhesive properties. It is easily removed with alcohol. Brackets were handmade by cutting and shaping pieces of vinyl clad steel wire. The brackets were used to hold the top and bottom in place and were fastened with tie-straps.

Air was supplied to the chamber after passing through a charcoal tube that was connected to the test chambers by 6 inch lengths of 3/8 inch diameter polyethylene tubes and a 1½ inch length of 3/8 inch diameter vinyl tubing connecting the polyethylene with the charcoal tube. The charcoal tube was seated in polyethylene quick tube disconnects. The polyethylene tubing and the vinyl tubing were connected with a 2-inch length of ¼ inch diameter polyethylene tube. Vinyl tubing was used as little as possible to reduce potential absorption of TCE and its byproducts. The air was removed from the test chamber with the same tubing configuration. On the

backside of the outline charcoal tube, only vinyl tubing was used. The vinyl tubing was connected to Whisper airflow control units. These airflow control units are normally used for controlling airflow on fish tanks. Each unit controlled 3 test chambers and by adjusting the needle-nose valve assembly the airflow for each chamber was balanced. The airflow control units were connected in series with one source of suction being provided by an air pump, a Gelman Instrument Company, model 13152, pressure/vacuum pump. A reservoir was placed between the pump and the first airflow control unit.

Each test chamber was numbered from 1 to 24 starting with the alfalfa (1-6), followed by soil (7-12), BG w/TCE (13-18), and finally BG w/o TCE (19-24) as depicted in Figure 3. Buffalo grass plants were biased for selection based on their appearance. Plants that looked like they had the best chance of surviving were selected for the BG w/TCE group (13-18). No other known bias was practiced during this experiment. The size of the chambers and the allocated space necessitated the chambers to be arranged in a U-shaped array with the light source more toward the bottom of the U-shape. A top view illustration is provided in Figure 3.

Chamber positions were ordered in sequence from 1 to 24 starting at the pump. With position numbers in place, chamber numbers were placed in a box and placed in position numbers as an unbiased volunteer randomly selected them. The first chamber number selected was placed in position 1 and this process continued until all chambers were positioned.

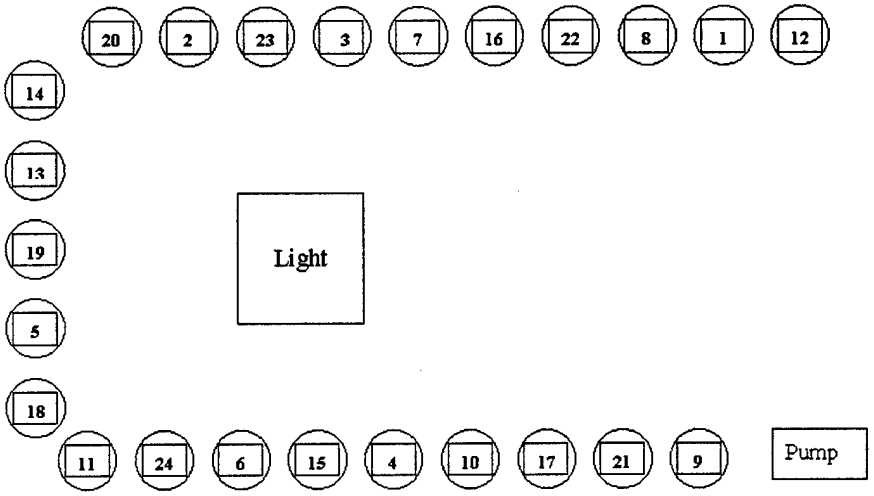

FIGURE 3. Top View of Experiment Setup.

During the equilibration period for adjustment to the test chambers (prior to sealing the test chambers), background samples were collected of water, sand, soil, gravel, and air to determine if TCE or its degradative products (dichloroethylene and vinyl chloride) were present. These samples were collected prior to adding TCE to the water. Blank and background samples as measured by gas chromatograph did not detect the presence of TCE, dichloroethylene (DCE), vinyl chloride (VC), and carbon tetrachloride (CT).

In addition to the background sample collection, additional water samples were collected for quality control purposes. The intent was to mimic the water being spiked with TCE and added to the test chambers. Following the first 12 hours of operation, air samples were collected and analyzed for TCE and its by-products. All of the

samples were analyzed at Armstrong Laboratory (AL) on Brooks Air Force Base located in San Antonio, Texas. AL is a certified laboratory.

To add water and water-TCE mixture to the test chambers, 15 inch lengths of 3/8 inch polyethylene tubes were attached to each stopcock and a polyethylene funnel was attached to the tubes. Water and water-TCE mixtures, as appropriate, were measured and poured into the funnel and entered the test chamber through the tube. To reduce potential losses of TCE while adding it to the chambers, the water-TCE mixture was mixed and all of the mixture was added to the chamber. Polyethylene tubing was selected to minimize the leaching of TCE into the tubing. With the introduction of TCE to the aquifer zone, the experimental chambers were monitored for the water level, adding controlled amounts as necessary, for approximately 6 weeks. The TCE used in this experiment was manufactured by Aldrich and had a purity of 99.5+. All of the water used throughout the experiment was distilled water purchased from Wal-Mart. Wal-Mart uses the Edwards Aquifer for their source of water and treats the water with steam distillation and ozonation. Experiment logs are provided in Appendix B.

Air samples were collected for the influent and effluent lines of the test chambers. The goal of this setup was to filter the in-going air and capture unbiased air samples exiting the chamber. Air samples were collected on SKC certified charcoal tubes (lot 2000). The sorbent is coconut charcoal with a 100-milligram (mg) front section followed by a 50-mg back section. The absorption potential of the charcoal tubes was incorrectly calculated. A decimal point error led to selecting an initial 14-

day sampling period, which was chosen to preclude sample breakthrough. Air samples were collected on days 1, 14, 26, 37, 40, and 43. A schematic view of the airflow for the test chambers is shown in Figure 4. All air samples were analyzed in the contract laboratory (AL) using appropriate NIOSH methods.

NIOSH method 1022 was used for analyzing TCE, methods 1003 and 1015 were used for DCE, method 1003 was also used for carbon tetrachloride, and method 1007 was used for vinyl chloride.

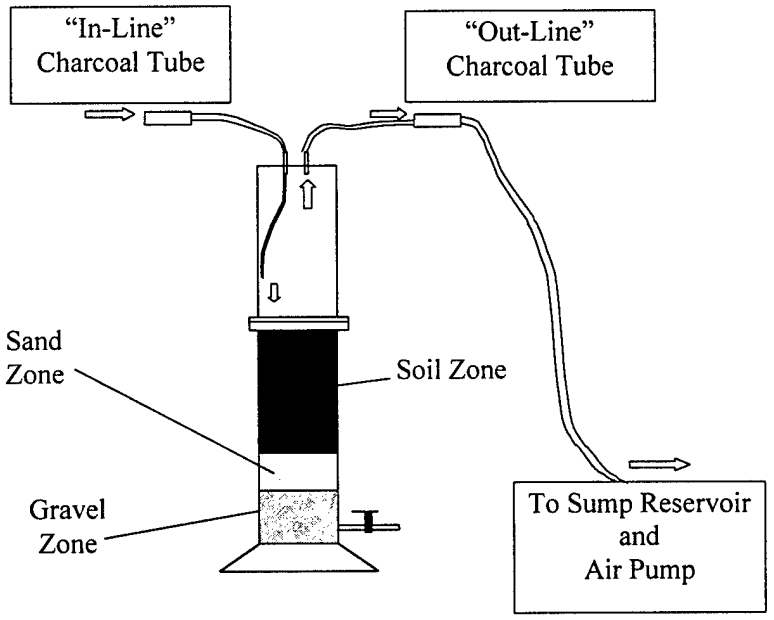

FIGURE 4. Schematic of Airflow for the Experimental Test Chamber. The charcoal tube filters the air entering the test chamber. No breakthrough occurred in the "in-line" samples. The "out-line" tubes were saturated with water and breakthrough of sample analytes occurred.

Every chamber was analyzed for TCE and its degradative products at the end of the 6-week period (experiment termination). The media analyzed included soil, water, plants, and air. The plant roots were not separately analyzed because we did not want to release TCE from the soil during the breakdown of the experiment. Root structure was left in place during soil collection.

Soil samples were collected at the beginning of the experiment and at the termination point. The samples were collected in 1-liter wide-mouth jars. Once collected, the samples were stored in a cold room at 4°C. No preservatives were added. The soil samples had three separate samples collected, one from the soil zone, one from the sand zone, and one from the gravel zone. Each sample was analyzed separately and the results were summed for one soil sample result. The soil zone samples were collected from the bottom of the soil column, which had more water than the top of the column. All of these samples were analyzed at the contract laboratory.

Water samples were collected at the beginning of the experiment (as discussed earlier) and at the termination point. The samples were collected in 40-mL vials with septum tops. The termination samples were collected by opening the stopcock at the bottom of the test chamber and capturing the first 40-mL that came out. Once collected, the samples were stored in a cold room at 4°C. No preservatives were added. All of these samples were analyzed at the contract laboratory.

The plant samples were collected at experiment termination. Once the grass was cut, it was weighed and stored in Thunberg tubes and in jars. The plant samples

in the jars were soaked in 3 mL of tetradecane and in very short period, absorbed the entire 3 mL of solvent. The plan was to slightly heat the jars and capture any volatiles that escaped the plant in the tetradecane. Since there was not any tetradecane remaining, nothing was done with the grass samples in the jars. The samples with the Thunberg tubes involved approximately 1.3 grams of grass (1 strand). The samples were manually injected into a Tracor 540 gas chromatograph utilizing an electron capture detector (ECD) analyzed based on the area under the peak for corresponding retention times. A control sample was established by injecting a tube with 1 μL of TCE and closing it (no grass). The control sample was diluted 100 times before the range was low enough to accurately quantify. Calibration samples were run along with the field samples. All of the grass samples resulted in TCE being detected, but at such a low number that it could not be quantified. Additionally, the samples of BG w/o TCE had the highest peaks suggesting that TCE may not have been detected at all. Instead, it could have been background noise with similar retention times.

Phase IV (Data Analysis and Reporting)

By far, the major expense associated with this project was the data analysis performed by a certified laboratory. In total, 267 air samples, 43 water samples, 85 soil samples, and 40 vegetative samples were analyzed for a cost of $8,850. The total retail cost would be closer to $70,000, but the contract laboratory (AL) agreed to perform the analysis at a steep discount. Vegetative samples were analyzed on Texas A&M University campus in Dr. Clement's laboratory (Scoates Hall) and Dr. He's

laboratory (Agronomy Field Laboratory) for a total cost of $2,000. A complete sample log is provided in Appendix D.

The samples analyzed at AL were paid for with Defense Environmental Restoration Account (DERA) funds provided by Humans Systems Center, Occupational and Environmental Health Directorate, Environmental Sciences Branch (HSC/OEHM). Vegetative analysis was paid for with the initial project funding provided by the Air Force Base Closure Agency.

The charcoal tubes used for air sampling were desorbed with carbon disulfide and auto-injected into a gas chromatograph (GC), adhering to approved NIOSH methods. Six calibration samples were run prior to running the field samples. The samples were auto-injected using 1 micro-liter (μL) and analyzed based on the area under the peaks at the appropriate retention times. Pertinent GC parameters for all of the analysis is provided in Table 2. NIOSH method 1007 had different parameters from the other methods. The GC temperature was 32°C for 4 minutes with no step increases. The total run time was 4 minutes per sample.

The water samples were analyzed using EPA method 624, Purge and Trap, utilizing a capillary column on a Hewlett Packard gas chromatograph/mass spectrometer (GC/MS) model 5972. Calibration samples were run with the sample analysis at the ratio of 10:1 (10 samples with 1 calibration). The samples were auto-injected using 1 micro-liter (μL) and analyzed based on the mass peak values. Along with the mass peak values, the corresponding ion peaks were also checked for the appropriate proportion.

TABLE 2. GC and GC/MS Data.

	Water & Soil	Air	Plant	Plant - Thunberg
Instrument (GC)	HP-5972	HP-5890	HP-5970B	Tracor-540
Column	HP-624	DB-5	HP-Ultra 2	DB-5MS
Type	Capillary DMPS	Capillary PHME	Capillary DMPS	Capillary Silicone
Detector	MS	FID	MS	ECD
Column Length	25 m	30 m	12 m	30 m
Inside Diameter	0.2 mm	0.32 mm	0.2 mm	0.53 mm
Film Thickness	1.12 μm	0.25 μm	0.33 μm	1.12 μm
Initial Temp	35°C	50°C	45°C	40°C
Hold time	4 min	2 min	1 min	5 min
Injection Temp	220°C	250°C	180°C	180°C
Step (°C/min)	8°C	15°C	10°C	10°C
Final Temp	180°C	160°C	75°C	100°C
Run Time	26 min	9.3 min	10 min	11 min
Type of Injection	Auto	Auto	Manual	Manual
Carrier Gas	He	He	He	N
Model/Part No.	HP Part No. 19091V-402	HP Part No. 19091J-413	HP Part No. 19091B-101	J&W Sci. 125-5032

Soil samples were analyzed with the same GC/MS as the water samples, but required EPA method 8260, volatiles, and a different sample preparation. Soil sample preparation involved combining 5 grams of a sample in a 40 mL vial with 10 mL of water. The sample was then placed in an auto-injector tray and injected with helium. The helium gas desorbs chemicals from soil and the chemicals become mixed with the water, which is injected into the GC/MS.

The vegetation samples were analyzed with two different procedures. Both procedures involved weighing fresh cuttings prior to addition to fixed amounts of tetradecane. The first procedure involved mixing the sample with the tetradecane in a blender and manually injecting 1 μL of the extract into a GC/MS (HP 5970B). Calibration samples were run along with the field samples analyzed based on the mass peak values. Along with the mass peak values, the corresponding ion peaks were also checked for the appropriate proportion.

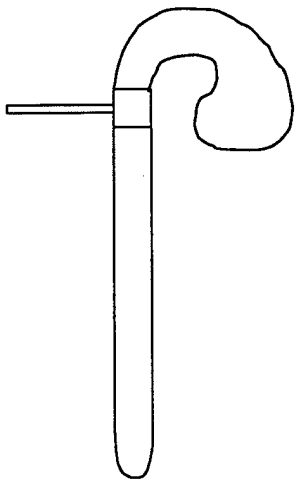

FIGURE 5. Drawing of Thunberg Tube.

The second procedure involved using Thunberg tubes to capture volatiles as they off-gassed from the plant. A Thunberg tube is shown in Figure 5. This procedure involved manually injecting 1 μL of the extract into a Tracor 540 GC utilizing an ECD. Calibration samples were run along with the field samples and

analyzed based on the area under the peak for the corresponding retention times. Control samples were used for each method. The control sample for the Thunberg tube validated the procedure whereas the control for the blender was not as convincing, suggesting loss of volatile TCE during the extraction process.

Statistical Methods

The experimental data from this experiment was analyzed to test the hypothesis that buffalo grass will improve the remediation TCE from an aquifer. Our sample data were analyzed using the general linear model procedure (GLM) within the SAS system. The analysis included ANOVA, MANOVA, and Scheffe's Test. The least square means and an error matrix were calculated. The least square means are used for the ANOVA test and the error matrix is used for the MANOVA test. The observations included the mass of TCE in grams recovered from air, soil, and water, and the amount of water given to each type of treatment. There were three treatments: alfalfa, soil, and buffalo grass with TCE (BG). Each treatment had 6 replicates. The statistical data are provided in Appendix E.

ANOVA. The ANOVA (analysis of variance) test conducted is a univariate test that compared treatment means with respect to one dependent variable. There were 2 degrees of freedom for the three types of treatments and 12 degrees of freedom for the error term. The P_{value} from the F-test is deemed statistically significant if this value is 0.05 or less.

MANOVA. The multivariate analysis of variance (MANOVA) first computes the partial correlation coefficients from the error matrix to determine if there is a linear relationship amongst the four variables. The P_{value} is displayed below the correlation coefficients and a value less than 0.05 indicates statistical significance.

Scheffe's Test. This test is considered the most conservative test that compares the treatment means for significant difference. It compares the means between treatments and indicates a significant comparison when the P_{value} is less than or equal to 0.05. The benefit of Scheffe's Test is that it identifies treatments that are significantly different.

RESULTS AND DISCUSSION

Bias

The data from buffalo grass without TCE were not included due to the bias for this group by having the least healthy plants. Additionally, the data from two alfalfa chambers and one soil chamber were not used. The data from 2 of the alfalfa chambers were not used because both columns were broken prior to starting this experiment and could not have the water-TCE mixture added through the stopcock. These chambers had the water-TCE mixture added from the top of the chamber. When initially saturating the aquifer layer, all of the test chambers received about 700 mL of water/water-TCE mixture. One of the soil chambers would not accept more than half this amount, so the remaining dose was administered from the top of the chamber. That one soil chamber was similarly discounted because it was top fed with the initial concentration of TCE and water. Lastly, the plant analysis data were not used for hypothesis-testing because there was no quantifiable data to compare. Thus, we have an unbalanced experiment with respect to treatments and replicates. Figure 6 shows the final number of test chambers used for the statistical analysis.

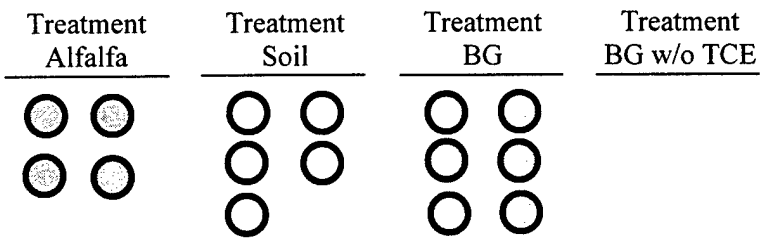

FIGURE 6. Test Chambers Analyzed by Treatment.

Lighting

A 1,000-watt Agrosun bulb was used for this experiment. The light seemed to have some effect on the plants since the alfalfa had blooming flowers and all of the chambers with plants had good growth, but it had minimum effect on the water usage rate and evapotranspiration. No noticeable difference was seen with the plants furthermost away from the light compared to the plants closest to it.

TCE Stress Tests

The plants were stress tested with various concentrations (1, 10, 100 ppm) of TCE mixed in the water to determine if an adverse effect would occur from the TCE. The stress tests were conducted over a 2-week period, which may not have been long enough to detect an observable effect. In a study conducted at the University of Kansas, it was reported that it takes two weeks before TCE even begins to degrade (21, 22). During the course of this experiment, one of our alfalfa plants died. In the University of Kansas study, 50 ppm was used in the aquifer, which suggests that the 20-ppm level used in this experiment should not have caused plant death. The major difference between our experiments was the test chamber. The University of Kansas used an open chamber that provided a better environment for the plants with respect to air exchanges and transpiration compared to our sealed chamber environment that resulted in visible effects on plant health. Our test chamber was designed to capture TCE for each plant and in doing so may not have provided enough breathing space for

the plants. The University of Kansas' chamber took area samples rather than individual plant data points.

Air Sample Analysis

Air samples were collected for the influent and effluent lines of the test chambers. The goal of this setup was to filter the in-going air and capture unbiased air samples exiting the chamber. Due to the high humidity levels within the chambers, the effluent samples did not capture the intended data because of sample breakthrough.

When the detected mass on the back section of a charcoal tube is 10% or more of the mass on the front section, the result is reported as having greater than 10% breakthrough. The reliability of the sample result is questionable. The majority of the effluent ("out-line") samples had greater than 10% breakthrough, and in many cases, the mass on the back section was 50% of that on the front sections. This clearly indicates that the air sample results for the "out-line" represent lower bound estimates on levels of TCE in the air. Breakthrough did not occur with any of the influent samples as reflected by the absence of mass on the backside of the charcoal tube.

The air samples were collected at different time intervals. After the experiment was operating for 12 hours, air samples were collected. The influent sample results were intended to be background data whereas the effluent results were supposed to be an indicator of how rapidly TCE would be released from the water. Initial results for the "in-line" background air were clean. The "out-line" samples also resulted in below detection limits with the exception of 4 air samples that detected VC

present. Vinyl chloride is a final byproduct of TCE degradation. Having VC present after a 12-hour period, 11 p.m. to 11 a.m., did not make sense. Especially when the night cycle is where the least amount of activity in plants is expected to occur. None of the remaining air samples collected throughout the experiment detected VC. The assumption is the VC was a residual product carried over from Phase II while plants were established in PVC columns because VC is suspected to leach from PVC.

The next three rounds of sampling were accomplished on day 12, day 25, and day 37. By the end of the first week, a high level of condensed moisture was present on inside surfaces of the test chambers. The airflow rate through the chambers was increased from 400 L/day to 570 L/day. This increase in airflow was intended to reduce the humidity inside the chambers, but did not have enough of an effect. Sample breakthrough had occurred in all of the "out-line" samples. Two more sets of air samples were collected at 3-day intervals prior to the termination of this project to capture better air sample results void of breakthrough. These samples also indicated that greater than 10% breakthrough occurred. Table 3 provides a summary of the air sampling data showing the severity of the breakthrough problem.

TABLE 3. Summary of Air Sampling Data.

Type	Total	Breakthrough	Mean TCE (μg)	Mean CT (μg)
"Out-line"	130	111	1,141	1,658
"In-line"	97	0	116	4,073
Blanks	30	0	0	0

CT = Carbon tetrchloride

The number of "out-line" samples that had breakthrough was significant. The overall means are provided for TCE and carbon tetrachloride in Table 3. The effluent samples that did not have breakthrough fall into two categories, 12-hour samples and 3-hour samples. There were 9 samples that did not have breakthrough during the first 12 hours of operation and then 10 more samples that did not have breakthrough during the 2 rounds of 3-hour sampling. Table 4 provides a closer look at the 3-day effluent samples that did not have breakthrough. All of these test chambers were eliminated from our analysis for various reasons that are discussed later in this section. The data from these air samples were not usable.

TABLE 4. Summary of the 3-Day Samples w/o Breakthrough.

Chamber Number	Chamber Number	Type
	1	Alfalfa
8	8	Soil
19		BG w/o TCE
20		BG w/o TCE
22	22	BG w/o TCE
23	23	BG w/o TCE

The sample breakthrough problem is illustrated in Figure 7. This figure illustrates that as TCE is added over time, our ability to recover the TCE is limited due to saturation of the media. Saturation of the charcoal tubes is closely related to breakthrough in this experiment. Essentially, each section of the charcoal tube will

hold only a definitive mass of TCE, and the back section will normally hold half the mass of the front section. In tubes showing breakthrough, mass captured on the back section ranged from 11% to 101% of the mass on the front section, indicating that saturation had occurred. Therefore, an unknown portion of TCE escaped without detection and quantification.

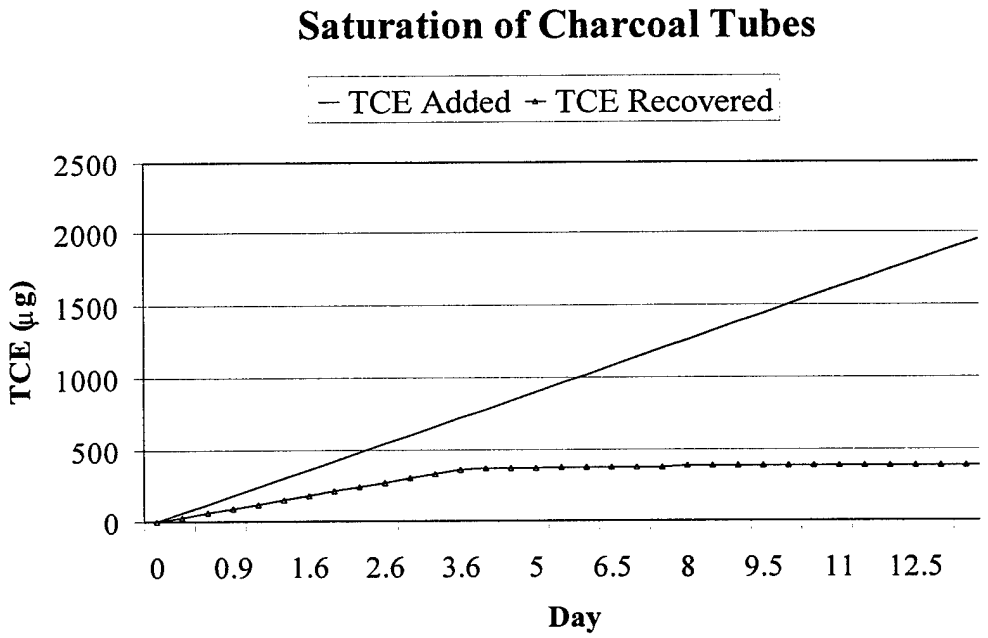

FIGURE 7. Saturation of Charcoal Tubes. The saturation of sampling media prevents the recovery of TCE over time.

Carbon tetrachloride (CT) was detected in both the "in-lines" and the "out-lines" of the second round of air sampling and thereafter. There is no known source for CT. Three weeks after the experiment was terminated, 6 more influent samples were collected and analyzed for TCE and CT. Again, CT was detected suggesting that

CT is present in the background air inside the greenhouse. The detection of carbon tetrachloride will be ignored for this experiment.

Air sample data for the treatments are shown in Table 5. The data clearly suggest that the samples for the plant chambers were less successful in capturing TCE. More TCE was input to alfalfa and BG chambers, but less detected after the first 12 days. Saturation of the air sample "out-lines", due to humidity and evapotranspiration, reduced the collection efficiency of the charcoal tubes. The amount of TCE detected in alfalfa chambers did not change very much after the sample taken on day 12, regardless of the sampling period. The data are similar for BG, but the soil column had reduced recovery during the first 3-day period (day 40). A closer review of all of the air samples with percentage of breakthrough is provided in Appendix D, Table D-2. In Table D-2 it is observed that, on day 8, a sample was collected from chamber

TABLE 5. Air Sample Data. The data are the mean and standard deviation for micrograms of TCE detected in the "out-line" air samples.

	Alfalfa		Soil		BG	
Day	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	ND*		ND*		ND*	
12	419.0	195.6	217.7	212.1	555.8	188.0
25	182.8	42.8	400.4	183.2	257.5	93.8
37	196.2	58.8	432.7	271.3	187.2	107.9
40	182.8	59.0	173.9	73.3	203.3	69.6
43	159.2	51.4	317.7	150.5	191.0	33.0

*ND— not detected at detection limit of 1.2 μg.

2 at the first sign of water in the line. Water became a problem from that point forward. Another important observation is that none of the effluent air samples detected levels of DCE or vinyl chloride. Any degradation of TCE should produce some DCE and VC. The absence of these compounds suggests that metabolic processes did not degrade TCE.

Soil Sample Analysis

Soil samples collected at termination detected fairly consistent levels of TCE across the treatment groups. TCE is more likely to be in the soil than the water, based on the affinity of TCE to polar molecules, and TCE is more likely to evaporate from surface water than soil (9). When the aquifer level decreases below saturation of the sand zone, TCE is more likely to leave the water and enter the air, and then migrate through the soil. Based on the means of the soil sample results compared to the added amount of TCE, shown in Table 6, the soil exhibits saturation. As more molecules of TCE enter the soil, other molecules of TCE are forced into the air.

TABLE 6. Mean TCE Recovery Values for Soil in Micrograms (μg).

Type	Mean	Std Dev	Low	High
Alfalfa	122	60	59	204
Soil	135	72	63	192
BG	102	43	47	175

The soil samples were collected from the bottom 3 inches of the soil columns. To collect the sample, the chamber was poured-out and the soil was extracted as one piece and then cut-up to fill the sample jar. Laboratory analysis used only 5 grams of each sample, usually from the top of the jar. Both sampling method and analysis procedure are possible sources of TCE loss.

Water Sample Analysis

The spiked water samples collected at the beginning of the experiment detected considerably lower levels of TCE than anticipated. Based on the level of TCE mixed in the water, the results should have been approximately 30,000 micrograms per liter (μg/L), but the highest result was only 335 μg/L. Based on observations over the course of this project, it is believed that the majority of the TCE remained on the bottom of the beaker and uniform mixing did not occur quickly enough to be captured in the sample. This was avoided during the experiment by mixing and adding all of the water-TCE mixture to each chamber it was prepared for. This procedure provided less opportunity for TCE to escape.

Water samples were collected after having TCE in the growth chamber water column for 43 days. The samples were grab samples from the growth chamber side tap near the bottom of the water column. Since TCE can sink to the bottom of water as observed during this experiment, it is possible that the remaining water in the chamber had higher TCE concentrations. An alternative approach to collect the water samples would have been to drian the water into a separate container, mix it, and then

take the sample. However, this could lead to cross contamination, volatization, and unequal mixing problems. As depicted by Table 7, the means of TCE detected in the water are fairly consistent.

TABLE 7. Mean TCE Recovery Values for Water in Micrograms (μg).

Type	Mean	Std Dev	Low	High
Alfalfa	436	256	90	636
Soil	628	179	402	822
BG	641	193	462	903

Vegetative Sample Analysis

The plant samples were collected at experiment termination. TCE was detected in all of the samples, but at levels lower than the quantification limit. Additionally, since the BG without TCE samples had the highest peaks (most TCE present), it is hard to say if TCE was being detected or if we were just getting background interference. The level of quantification required at least 32 μg/mg of wet plant. The actual results ranged from 0.00128 to 0.00738 μg/mg of wet plant for the plants that received TCE. These results range from approximately 50 to 230 times lower than the quantification limit. As a control, a Thunberg tube was injected with 1 μL of TCE and closed (no grass). This sample had to be diluted 100 times before the range was small enough to quantify. The Thunberg tube was thus shown to be a valid procedure for detecting off-gassing of TCE.

Statistical Analysis

Statistical power calculations are computed to determine the probability of correctly rejecting the null hypothesis when the null hypothesis is false. Increasing the power increases the probability of rejecting the null when it is false or not rejecting the null when it is not false. Said simply, the power is the probability of recognizing a true difference between two groups. Figure 8 shows the options and desired outcomes.

	Conclude the Hypothesis is:	
	True	False
Hypothesis is True	☺ **Good**	☹ Bad Type II error
Hypothesis is False	☹ Bad Type I error	☺ **Good** Power (1-β)

FIGURE 8. Statistical Power. Goal is to correctly conclude results.

The power of a statistical test is determined by three factors: 1- the magnitude of the type I error α; 2- the size of the desired difference δ; and 3- the sample size of the study. As the size of the type I error becomes smaller, the power also becomes smaller. That is, as α becomes smaller, the allowance to make a mistake becomes smaller and, therefore, it becomes harder to reject the null hypothesis. The same is true for δ. As δ increases, it becomes easier to detect a difference between the treatments and, therefore, the power increases. Lastly, as the number of replicates

increase, the variability of the measure of exposure effect decreases. In other words, increasing the number of replicates increases the power because it is easier to distinguish differences in data points. The power of a study is actually the complement of the type II error β. When a decision is made not to reject the null hypothesis when there actually is a difference between treatments, a type II error has occurred (26).

The power for this experiment was calculated after termination as 0.28. Based on the above understanding of power, we had approximately 28% chance of actually making the correct decision. Increasing the power for future experiments can be accomplished in a number of ways. The easiest would be to increase the α of the experiment. The typical value of α is 0.05 (5%), so increasing it to 15% would increase the likelihood of correctly rejecting the null hypothesis when it is truly false. Another way to increase the power is to increase the number of replicates. The number of replicates may be limited by budgetary constraints and the number that can be managed. Lastly, designing an experiment that will test for a large difference will increase the probability of correctly rejecting the null hypothesis. Optimizing all the factors within allocated resources, natural variability, and significance required would provide the highest power for the experiment.

The ANOVA test resulted with a statistical significance with the dependant variable water (the amount of water-TCE mixture added). This indicates that the amount of water-TCE added is statistically different between the soil, alfalfa, and BG

chambers, but does not indicate which one(s) is/are significantly different. The data are shown in Table 8.

TABLE 8. ANOVA Analysis of Dependent Variable Water.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3008050.42	1504025.21	29.99	0.0001
Error	12	601739.58	50144.97		
Corrected Total	14	3609790			

R-Square	C.V.	Root MSE	Water Mean
0.833303	14.057	223.931	1593

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	2	3008050.42	1504025.21	29.99	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	2	3008050.42	1504025.21	29.99	0.0001

The MANOVA test indicated there was a small amount of linear correlation between TCE in water (Y2) and TCE in soil (Y3). Although Y2 and Y3 are somewhat correlated, Y2 and Y3 were evaluated together with the MANOVA and did not find significant differences with respect to the treatments, therefore, the ANOVA analysis was still valid.

The Scheffe's Test revealed that the soil treatment was statistically different from both alfalfa and BG treatments with respect to water/TCE consumption, and that

the alfalfa and BG treatments were statistically equivalent. The soil treatment consumed less water and the data are shown in Table 9.

TABLE 9. Scheffe's Test for Dependent Variable Water.

Alpha= 0.05 Confidence= 0.95 df= 12 MSE= 50144.97
Critical Value of F=3.88529

Treatment	Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
1	3	-258.4	144.6	547.5	
1	2	610	1028.8	1447.5	***
3	1	-547.5	-144.6	258.4	
3	2	506.2	884.2	1262.2	***
2	1	-1447.5	-1028.8	-610	***
2	3	-1262.2	-884.2	-506.2	***

The statistical analysis indicated that there was no difference with the detection of TCE between the samples taken from the chambers with plants and without plants (soil). The analysis also indicated that there was a significant difference between the amount of water added to chambers with plants and those without plants. This significant difference with water added also correlated to TCE added as seen in Figure 9, and demonstrated that phytoremediation could have occurred through the mechanism of phytovolatilization. Other descriptive statistics are provided in Figures 10–12, which show the mean and standard deviation for each observation.

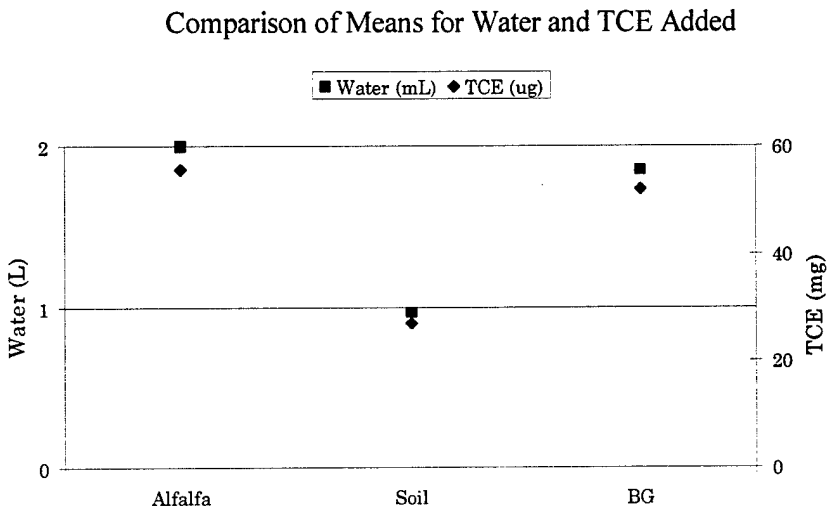

FIGURE 9. Comparison of Means for Water and TCE Added. This diagram demonstrates the direct correlation between water added with TCE added.

Mass Balance

The mass balance of this experiment was computed and is presented in Table 10. The data shown only accounts for a small percentage of the total TCE added during the course of this experiment. There are many sources of error in research and part of any experiment is to identify the errors and eliminate as many as possible. Some of the errors were removed before the experiment, but others were discovered during the experiment. Some of the possible sources of error already discussed in this paper include losses during the injection of TCE, breakthrough of air sampling media, losses during collection, and losses during analysis. There is another potential source of error associated with this experiment and that is the potential for biotransformation.

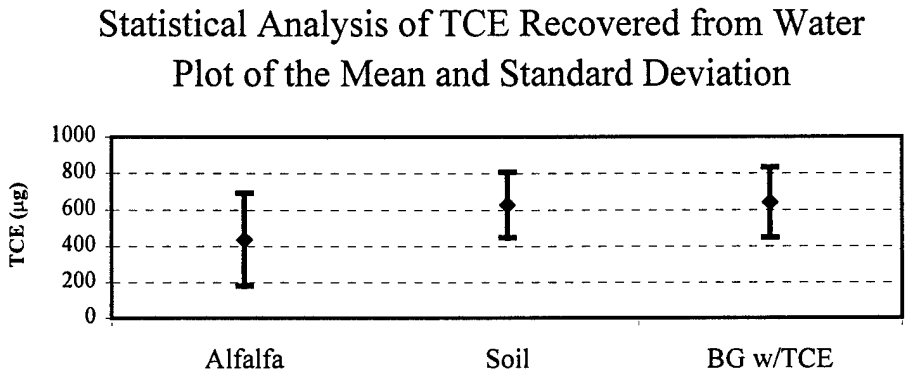

FIGURE 10. Recovered TCE (µg) from Water.

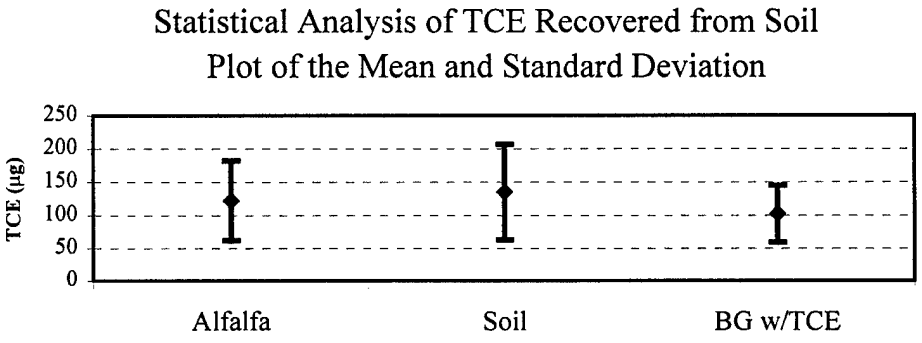

FIGURE 11. Recovered TCE (µg) from Soil.

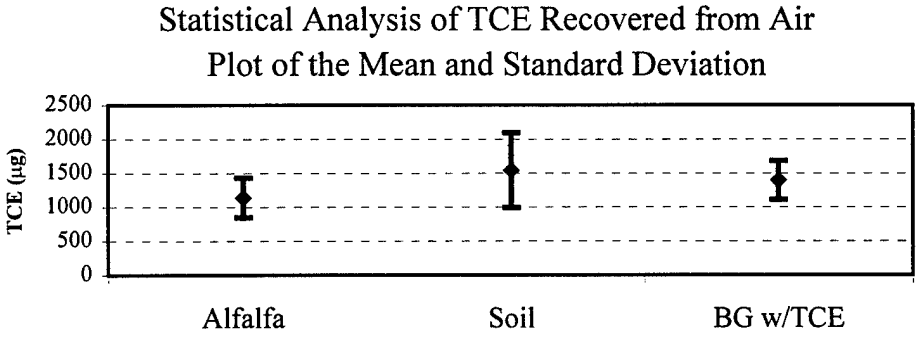

FIGURE 12. Recovered TCE (µg) from Air.

TABLE 10. Mass Balance Computation.

	Recovered TCE in Micrograms		
	Alfalfa	Soil	Buffalo Grass
Air	1,140	1,542	1,395
Soil	122	135	102
Water	436	628	641
Total Out:	1,698	2,306	2,137
Total In:	55,580	26,880	51,963
Percentage:	3%	9%	4%

Like humans, plants have the ability to transform TCE into trichloroacetic acid and trichloroethanol (6, 23). It is possible that the plants converted TCE into these products prior to excreting them. Our study did not monitor these chemicals.

Overall, the data indicates that the water concentration remained similar at P: 0.29 level suggesting no metabolic bias to remove TCE faster than water. The soils used during this experiment were from the same batch. Therefore, a similar response to similar stimuli can be expected. However, differences can be expected between soils with and without roots. The air sampling data equivalence is explained by the saturation of the media. The missing TCE can only be accounted for by speculation.

CONCLUSIONS

The primary purpose for this experiment was to evaluate the null hypothesis that buffalo grass would not aid with the remediation of groundwater contaminated with trichloroethylene (TCE). To accomplish this, a mass-balance experiment was designed to determine the extent of TCE remediation/degradation that occurs through buffalo grass. Plants were stress-tested prior to conducting the experiment to ensure that the level of 20 ppm water-TCE mixture would not affect the plant health. The stress tests indicated a NOEL to be at least 100 ppm TCE in water. At the termination of the experiment, air, soil, water, and plant tissue samples were collected. Valid data were analyzed to evaluate the null hypothesis. The statistical analysis showed no significance between treatments with respect to TCE detected, but did show significance for the amount of the water-TCE mixture added to maintain the simulated aquifer.

The data clearly shows that more TCE was better removed from the chambers with plants than without plants. One possible conclusion is that TCE was removed via phytovolatilization. However, the TCE levels in the water and soil were nearly equivalent at the termination of this experiment suggesting that TCE may have escaped via preferential pathways through the soil, perhaps near plant roots.

During the course of this project, there were many potential sources of error that could have interfered with the outcome. The statistical power was maximized within the budgetary constraints by increasing the number of replicates in each

treatment to 6. By the end of the experiment, only 1 treatment (buffalo grass) had all 6 replicates remaining. The data that was analyzed also had potential sources of error. The most significant problem with the data is the breakthrough that occurred with the air sampling media. The error with the air sampling contributed to the inability to balance the TCE added with the TCE detected. However, even if all of the missing TCE was attributed to the loss from breakthrough, it does not explain the mechanism of action or the similarity of sample results for the water and soil.

A simple review of descriptive statistics is adequate to determine no significance occurred between test groups with the exception of the amount of water/TCE added to each group. In addition to the descriptive statistics, the data were analyzed using inferential statistical analysis including ANOVA, MANOVA, and Scheffe's tests. All of these tests indicated that there is no significance to indicate buffalo grass aids with the remediation of TCE. Based on the data suggesting there is no difference between the treatments and the lack of evidence for a distinctive mechanism for remediation, the null hypothesis is not rejected.

A health risk assessment was not accomplished because there is no evidence to suggest remediation will occur in field conditions.

Project Design

With the completion of this pilot study and a thorough review of the experiment, a brief list of recommendations is provided for future experiments.

Obviously these recommendations can only be accomplished with a well-funded project.

a. Perform daily measurements of the TCE concentration to closely monitor changes and identify a mechanism of action that removes the TCE. The soil plays a significant role here and needs to prevent TCE from escaping via preferential pathways.
b. Maintain the simulated aquifer level with water and water/TCE mixture.
c. Provide relief of the humidity/transpiration in the chambers.
d. Modify the sampling method to account for the moisture/humidity in the air.

Future Direction

Phytoremediation is still a new field with unlimited opportunity for growth. Carefully selecting the right plant can lead to the remediation of contaminated site at a fraction of the cost incurred by mechanical remediation techniques. As an added benefit, phytoremediation is likely to obtain community acceptance more rapidly than installing an air stripping tower or bioreator.

As with other remediation techniques, it is likely that combined technologies will be more effective than sole application of any one. TCE remediation is often accomplished by co-metabolic remediation because previous research has shown that TCE is not easily degraded. However, the latest research shows that new hybrid poplars appear to break down TCE to carbon and salts.

The root structure is an important consideration when pumping water and/or contaminants more than a few feet. The alfalfa plant had a very deep and thick root structure, which suggests it would be a good candidate for phytoremediation. As mentioned earlier, plants in the legume family may work the best for breaking chlorinated solvents such as TCE.

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APPENDIX A

PUMP-AND-TREAT METHODS

The list of methods comes directly from the Ground Water Pumping Section of the Remediation Technologies Screening Matrix and Reference Guide, Version 3.0. The data was accessed on 29 March 1997 from their website (25).

Bioreators. Contaminants in extracted ground water are put into contact with microorganisms in attached or suspended growth biological reactors. In suspended systems, such as activated sludge, contaminated ground water is circulated in an aeration basin. In attached systems, such as rotating biological contractors and trickling filters, microorganisms are established on an inert support matrix.

Constructed wetlands. The constructed wetlands-based treatment technology uses natural geochemical and biological processes inherent in an artificial wetland ecosystem to accumulate and remove metals and other contaminants from influent waters.

Adsorption/Absorption. In liquid adsorption, solutes concentrate at the surface of a sorbent, thereby reducing their concentration in the bulk liquid phase. The most common adsorbent is granulated activated carbon (GAC) (see Technology Profile No. 4.51). Other natural and synthetic adsorbents include: forage sponge, lignin adsorption, sorption clays, and synthetic resins.

Air Stripping. Volatile organics are partitioned from ground water by increasing the surface area of the contaminated water exposed to air. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.

Gran**ulated Activated Carbon (GAC)/Liquid Phase Carbon Adsorption.** Ground water is pumped through a series of canisters or columns containing activated carbon to which dissolved organic contaminants adsorb. Periodic replacement or regeneration of saturated carbon is required.

Ion Exchange. Ion exchange removes ions from the aqueous phase by the exchange of cations or anions between the contaminant and the exchange medium. Ion exchange materials may consist of resins made from synthetic organic materials that contain ionic functional groups to which exchangeable ions are attached. They also may be inorganic and natural polymeric materials. After the resin capacity has been exhausted, resins can be regenerated for re-use.

Precipitation/Coagulation/ Flocculation. This process transforms dissolved contaminants into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration. The process usually uses pH adjustment, addition of a chemical precipitant, and flocculation.

Separation. Separation processes seek to detach contaminants from their medium (i.e., groundwater and/or binding material that contain them). Ex situ many processes can perform separation of waste stream: (1) distillation, (2) filtration/ultrafiltration/microfiltration, (3) freeze crystallization, (4) membrane prevaporation and (5) reverse osmosis.

Sprinkler Irrigation. Wastewater is distributed over the top of the filter bed through which wastewater is trickled. The organic contaminants in wastewater are degraded by the microorganisms attached to the filter medium.

APPENDIX B

EXPERIMENT LOG

1 Aug to 5 Sep	Met with various people and discussed project. ■ Dr. White at Crop Science Laboratory recommended watering grass 2x/day ■ Supplied buffalo grass and recommended cutting roots ■ Suggested roots will grow back within 6 weeks
8 Sep	Transplanted buffalo grass ■ removed all soil and debris with garden hose ■ cut roots ■ added distilled water w/ nutrients (1/2 teaspoon/gal) ■ finished at 3 p.m. so only 1 watering today
9 Sep	Added water 2x today (morning and late afternoon) ■ Grass doesn't look good ■ Need to get back-up columns quickly
10 Sept	Watered columns only 1x today ■ Purchased another 10' piece of PVC pipe to make back-up columns ■ Plan to transplant more grass next week and start growing alfalfa
30 Sep	Transplanted 10 more columns of buffalo grass ■ Moved columns to big table in greenhouse ■ Planted alfalfa seed
1 Oct	Obtained beakers for TCE Stress tests ■ Plan on 3x BG and alfalfa for each stress level ■ Hypothesis is TCE will produce a observable effect
4 Oct	Started TCE Stress tests ■ Each beaker was given 200 mL of water (18 beakers total) ■ Group 1 has 1 ppm TCE ■ Group 2 has 10 ppm TCE ■ Group 3 has 100 ppm TCE
5 Oct to 20 Oct	Continued to supply water and nutrients to columns ■ Transferred 2 extra buffalo grass columns to soil columns to balance Experiment (BG – 20 columns, soil – 6 columns, alfalfa – 6 columns) ■ Designed and ordered experimental test chambers
21 Oct	Terminated Stress Tests ■ Plant tissue was cut and placed in jars for analysis ■ Soil remained in place for further testing if required
10 Dec	Alfalfa has budding flowers (purple) ■ Alfalfa does not tolerate drought conditions ■ Recovers quickly to water
28 Dec	Transferred all columns into test chambers and added water

	■ Water not moving quickly through soil/sand barrier
29 Dec	■ Tough time opening the stopcocks ■ May be indicative of trapped gas
31 Dec	■ Inserted gas relief lines in columns which would not allow air to pass
1 Jan	■ All 6 Alfalfa and 3 soil chambers operational
2 Jan	■ Collected air samples for the initial conditions
4 Jan	■ All test chambers are up and running
6 Jan	■ Inadvertently injected TCE in columns 20 & 24
8 Jan	■ Chamber 2 had stopcock broken ■ Water building in many lines ■ Chamber 8 had effluent hose disconnected ■ Air pump working well (just below 5 psi) ■ Top of columns warm compared to bottoms
10 Jan	■ Chambers 20, 18, 11, 10, & 6 have water in tubes ■ 17, 16, 15, 14, 13, 12, 8, 7 all have moisture in tubes
11 Jan	■ Most of the columns and lines have dried-up w/ increased flow rate ■ Attempted to install charcoal tube between pump and sump reservoir, but the vacuum demand was to excessive ■ Plant growth looks good; some plants are hitting top of chambers
12 Jan	■ All columns have moisture again ■ Adjusted flow rates for 8-13 secs/80mL ■ Mold in chambers 21, 17, 6, 24, 18, 5, 19, 13, 14, 20, 2, 3, 16, 22 1 ■ Top piece of chamber 2 broke while I was in the greenhouse – no apparent reason
13 Jan	■ Chambers have less moisture
16 Jan	■ Moisture content seems to be related to outside temperatures; the warmer it is, the more moisture found in the chambers
17 Jan	■ Temperature of chambers is warm ■ Lots of moisture ■ Changed bottom cap on Chamber 1; helps keep the water in the chamber and prevents the air from being sucked in the bottom ■ Algae in 1, 8, 23, 2, 20, 17, 4 ■ Minor algae growth in 18, 11, 24, 5, 21, 9, 5, 19, 13, 14, 3, 7, 16, 22, 12 ■ Flower blooming in chamber 1
20 Jan	■ Mild growth on inside of glass in 1, 3 ■ Flowers blooming in 1, 3 , 5 ■ All alfalfa plants are hitting the top of the chambers
24 Jan	■ Mold film covering ½ of 3
1 Feb	■ Weeds growing in chambers 12, 7, 11 ■ Minor growth in 9, 10 ■ 6 has little white crystal structures on inside of chamber & on some plant leafs ■ mold continues to grow

4 Feb	■ 2, 3, & 5 appear brown – dried out? ■ 17 has bugs
8 Feb	■ Photograph of (6, 15, 4), (5), (14, 20, 2, 23, 3, 7) ■ Slight recovery from mold ■ Heavy weed growth in 7 ■ Changed out tubes
14 Feb	■ Experiment termination ■ Vacuum still good; approximately at 3 ■ Low grass height/volume: 21, 24, 14, 23, 22 ■ High Grass height/Volume: 16, 20, 19, 6, 15, 4, 17 ■ Weeds: 10 – low, 11 & 12 – medium, 7 – high ■ Dead plant: 5 looks worst, 6 - 20 % dead, 3 – some green ■ Photographs: (21-1), (8-22), (16-7), (3-23), (2-20), (14-13), (19-5), (18-11), (24-6), (15-4), (10-17), (21-9) ■ Thumberger tubes prepared with 2mL of tetra decane ■ Vegetative sample jars prepared with 3 mL tetra decane ■ Shut-down at 1905

APPENDIX C

EXPERIMENTAL DATA

This section provides detailed data on all aspects of the experiment. The TCE and water added, measure of airflow rates, complete review of sample results by treatment, and GC results are all included.

Contents:

TABLE C-1.
GC Data for Plant Tissue Analysis

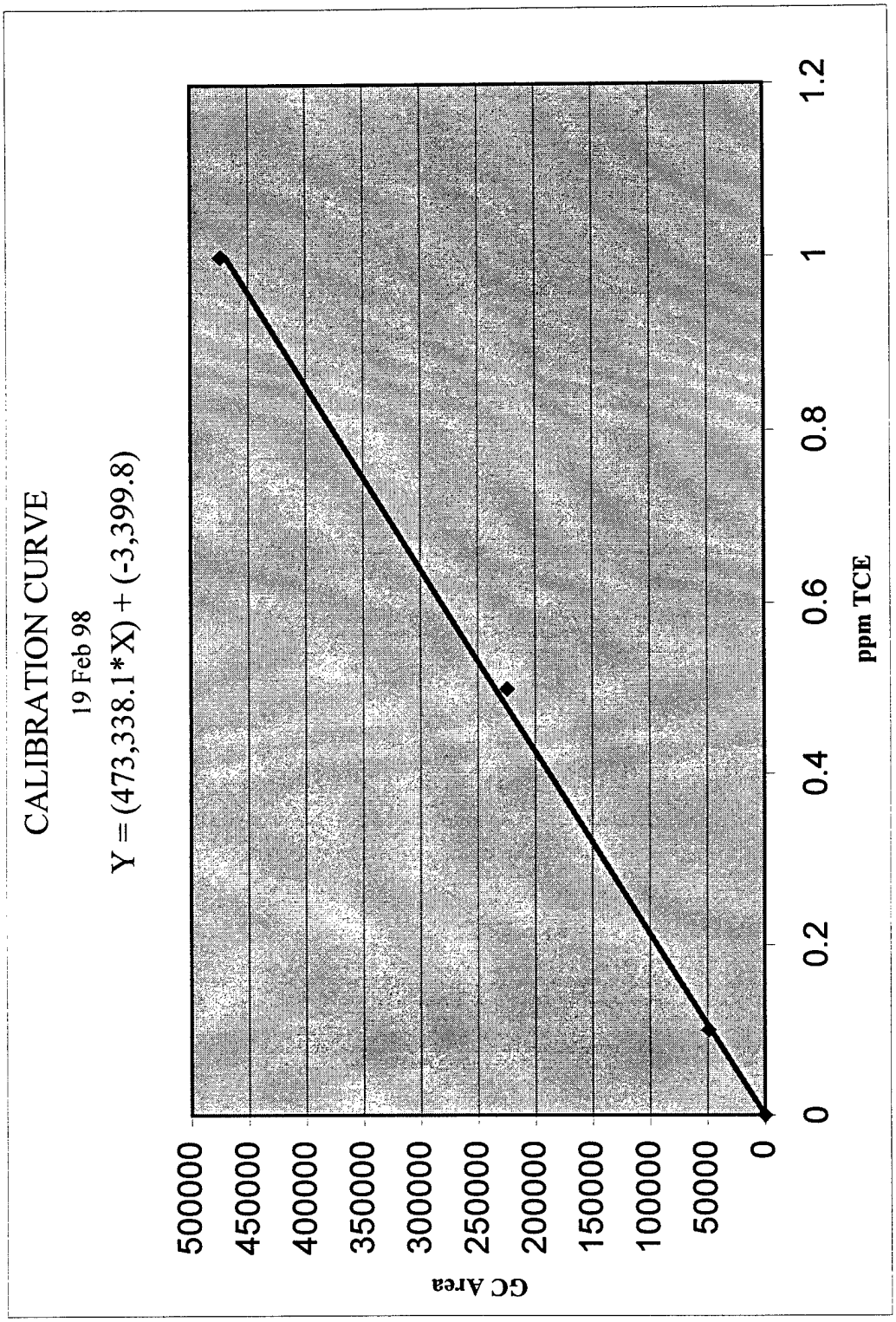
Sample Bin No.	Injection Date	Injection Quantity (uL)	Sample ID	GC Area A(GC)	Response Time (min.s)	From Calibration Curv Slope (m)	From Calibration Curv Y-Inter (b)	A(GC) - (b) /(m) ppm TCE	TCE in 2 mL TD (uL)	Wt. Of TCE (ug)	Plant Weight in grams Used	Plant Weight in grams Total	Used / Total Ratio	Total TCE (ug)
3	19-Feb	1	0.1 ppm TCE	53,220	3.5	471,145	0	0.11	0.0002	0.316	1	1	1	0.316
4	19-Feb	1	0.5 ppm TCE	222,458	3.66	471,145	0	0.47	0.0009	1.322	1	1	1	1.322
5	19-Feb	1	1.0 ppm TCE	458,598	3.71	471,145	0	0.97	0.0019	2.725	1	1	1	2.725
6	19-Feb	1	0.1 ppm TCE	10,855	3.65	471,145	0	0.02	0.0000	0.065	1	1	1	0.065
7	19-Feb	1	0.1 ppm TCE	44,471	3.72	471,145	0	0.09	0.0002	0.264	1	1	1	0.264
8	19-Feb	1	0.5 ppm TCE	226,399	3.77	471,145	0	0.48	0.0010	1.345	1	1	1	1.345
9	19-Feb	1	1.0 ppm TCE	489,137	3.75	471,145	0	1.04	0.0021	2.907	1	1	1	2.907
10	19-Feb	1	19	728	3.76	471,145	0	0.00	0.0000	0.004	1.31	40	31	0.132
11	19-Feb	1	Control	28,305,410	3.86 & 5.0	471,145	0	60.08	0.1202	168.218	1	1	1	168.218
12	19-Feb	1	1	300,614	3.91	471,145	0	0.64	0.0013	1.787	1.45	37	26	45.588
13	19-Feb	1	2	0	0	471,145	0	0.00	0.0000	0.000	0.92	26	29	0.000
14	19-Feb	1	3	457	3.28	471,145	0	0.00	0.0000	0.003	1.19	42	35	0.096
15	19-Feb	1	4	477	3.98	471,145	0	0.00	0.0000	0.003	1.09	74	68	0.192
16	19-Feb	1	5	447	4.01	471,145	0	0.00	0.0000	0.003	0.12	21	175	0.465
17	19-Feb	1	6	370	4.05	471,145	0	0.00	0.0000	0.002	1.33	84	63	0.138
18	19-Feb	1	7	0	0	471,145	0	0.00	0.0000	0.000	1.07	29	27	0.000
19	19-Feb	1	11	237	4.09	471,145	0	0.00	0.0000	0.001	1.22	14	11	0.016
20	19-Feb	1	1	314	4.14	471,145	0	0.00	0.0000	0.002	1.45	37	26	0.048
21	19-Feb	1	13	314	4.14	471,145	0	0.00	0.0000	0.002	1.14	72	63	0.118
1	19-Feb	3	14	3,038	4.08	471,145	0	0.00	0.0000	0.006	1.15	73	63	0.382
2	19-Feb	3	0.5 ppm TCE	1,239,791	4.24	471,145	0	0.88	0.0018	2.456	1	1	1	2.456
3	19-Feb	3	15	2,259	4.4	471,145	0	0.00	0.0000	0.004	1.17	70	60	0.268
4	19-Feb	3	16	3,723	4.52	471,145	0	0.00	0.0000	0.007	1.27	69	54	0.398
5	19-Feb	3	17	2,340	4.66	471,145	0	0.00	0.0000	0.005	1.15	73	63	0.294

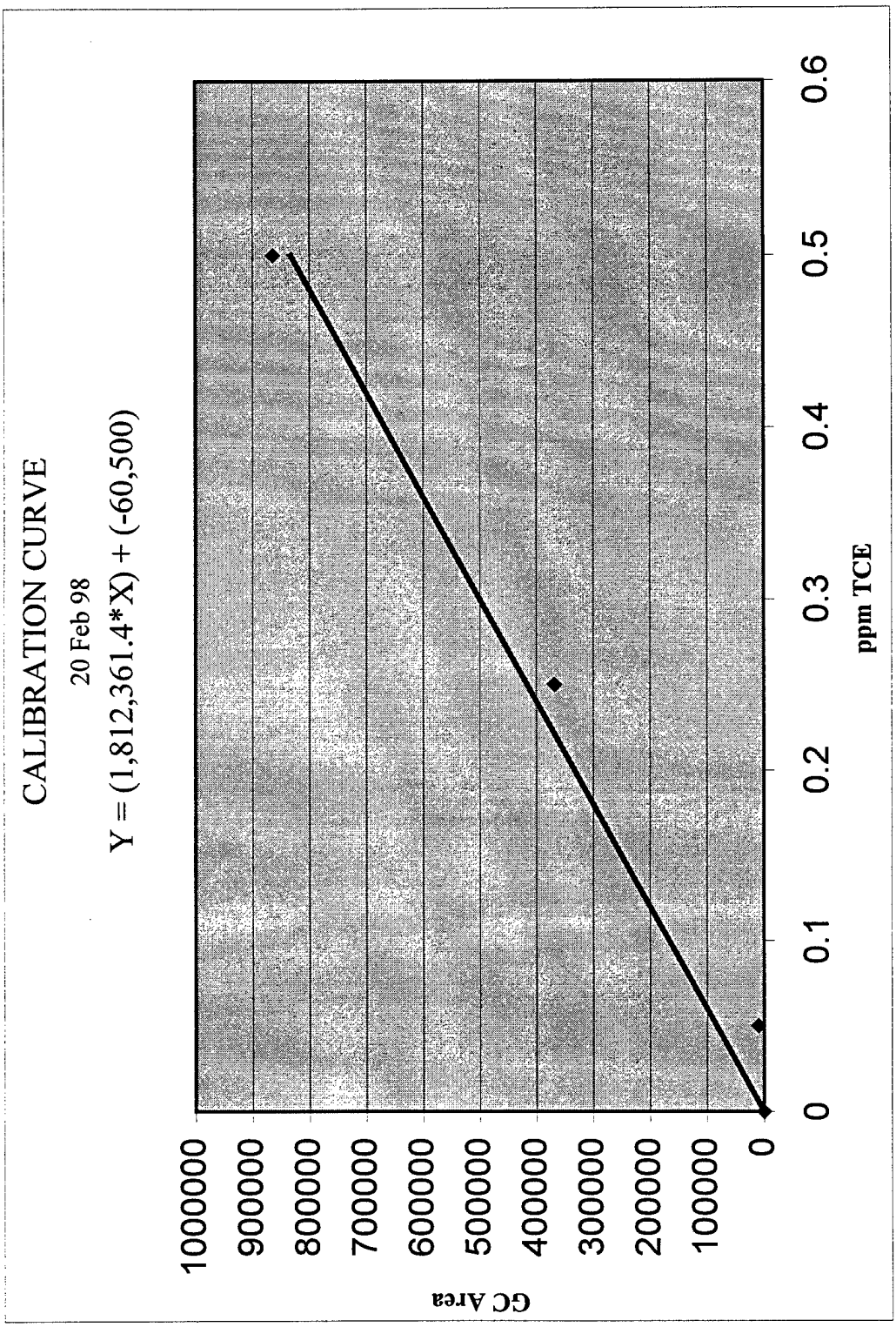
TABLE C-1. (Cont'd)

Sample Bin No.	Injection Date	Injection Quantity (uL)	Sample ID	GC Area A(GC)	Response Time (min.s)	From Calibration Curv		A(GC) - (b) /(m)	TCE in 2 mL TD (uL)	Wt. Of TCE (ug)	Plant Weight in grams		Used / Total Ratio	Total TCE (ug)
						Slope (m)	Y-Inter (b)	ppm TCE			Used	Total		
6	20-Feb	1	.25 ppm TC	368,137	4.73	1,782,036	0	0.21	0.0004	0.578	1	1	1	0.578
7	20-Feb	1	0.5 ppm TCE	864,389	4.61	1,782,036	0	0.49	0.0010	1.358	1	1	1	1.358
8	20-Feb	1	0.1 ppm TCE	82,299	4.77	1,782,036	0	0.05	0.0001	0.129	1	1	1	0.129
9	20-Feb	3	18	4,824	4.83	1,782,036	0	0.00	0.0000	0.003	1.09	58	53	0.134
10	20-Feb	3	20	*2,437*	*4.95*	1,782,036	0	0.00	0.0000	0.001	1.31	85	65	0.083
11	20-Feb	3	21	*2,902*	*5.01*	1,782,036	0	0.00	0.0000	0.002	1.63	71	43	0.066
12	20-Feb	3	22	*1,692*	*5.16*	1,782,036	0	0.00	0.0000	0.001	1.46	42	29	0.025
13	20-Feb	3	23	*3,458*	*5.36*	1,782,036	0	0.00	0.0000	0.002	1.12	50	45	0.081
14	20-Feb	3	24	*2,237*	*5.46*	1,782,036	0	0.00	0.0000	0.001	0.95	40	42	0.049
15	20-Feb	1	.025 ppm TC	49,056	5.58	1,782,036	0	0.03	0.0001	0.077	1	1	1	0.077
16	20-Feb	1	.05 ppm TC	9,374	5.54	1,782,036	0	0.01	0.0000	0.015	1	1	1	0.015
17	20-Feb	3	Tetra Decane	***4,349***	***4.2***									
18	20-Feb	1	.05 ppm TC	10,733	5.66	1,782,036	0	0.01	0.0000	0.017	1	1	1	0.017
19	23-Feb	1	.025 ppm TC	17,914	4.78	187,826	0	0.10	0.0002	0.267	1	1	1	0.267
20	23-Feb	1	.05 ppm TC	18,875	4.76	187,826	0	0.10	0.0002	0.281	1	1	1	0.281
21	23-Feb	2	.025 ppm TC	37,282	4.76	187,826	0	0.10	0.0002	0.278	1	1	1	0.278
22	23-Feb	1	.05 ppm TC	24,256	4.41	187,826	0	0.13	0.0003	0.362	1	1	1	0.362
23	23-Feb	2	.05 ppm TC	79,572	4.78	187,826	0	0.21	0.0004	0.593	1	1	1	0.593
24	23-Feb	1	0.5 ppm TCE	24,117	4.78	187,826	0	0.13	0.0003	0.360	1	1	1	0.360
25	23-Feb	1	1.0 ppm TCE	21,134	4.94	187,826	0	0.11	0.0002	0.315	1	1	1	0.315
26	23-Feb	1	0.1 ppm TCE	57,519	4.93	187,826	0	0.31	0.0006	0.857	1	1	1	0.857
27	23-Feb	1	0.5 ppm TCE	100,712	4.95	187,826	0	0.54	0.0011	1.501	1	1	1	1.501
28	23-Feb	1	1.0 ppm TCE	205,196	4.95	187,826	0	1.09	0.0022	3.059	1	1	1	3.059

TABLE C-1. (Cont'd)

Sample Bin No.	Injection Date	Injection Quantity (uL)	Sample ID	GC Area A(GC)	Response Time (min.s)	From Calibration Curv		A(GC) - (b) /(m)	TCE in 2 mL TD	Wt. Of TCE	Plant Weight in grams		Used / Total Ratio	Total TCE (ug)
						Slope (m)	Y-Inter (b)	ppm TCE	(uL)	(ug)	Used	Total		
29	23-Feb	1	0.01 Control	270,075	4.95	187,826	0	1.44	0.0029	4.026	1	1	1	4.026
30	23-Feb	1	0.1 Control	4,665,890	4.94 & 5.9	187,826	0	24.84	0.0497	69.556	1	1	1	69.556
31	23-Feb	1	.025 ppm TC	47,372	4.92	187,826	0	0.25	0.0005	0.706	1	1	1	0.706
32	23-Feb	1	.05 ppm TC	18,006	4.87	187,826	0	0.10	0.0002	0.268	1	1	1	0.268
33	23-Feb	1	13	3,867	5	187,826	0	0.02	0.0000	0.058	1.14	72	63	3.656
34	23-Feb	1	.05 ppm TC	251,860	5.07	187,826	0	1.34	0.0027	3.755	1	1	1	3.755
35	23-Feb	3	14	3,518	5.08	187,826	0	0.01	0.0000	0.017	1.15	73	63	1.110
36	23-Feb	3	15	2,824	5.19	187,826	0	0.01	0.0000	0.014	1.17	70	60	0.840
37	23-Feb	3	16	6,533	5.28	187,826	0	0.01	0.0000	0.032	1.27	69	54	1.751
38	23-Feb	3	17	2,876	5.4	187,826	0	0.01	0.0000	0.014	1.15	73	63	0.907
39	23-Feb	3	18	4,745	5.57	187,826	0	0.01	0.0000	0.024	1.09	58	53	1.250


CALIBRATION CURVE
19 Feb 98
Y = (473,338.1*X) + (-3,399.8)
GC Area
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
0
0.2
0.4
0.6
0.8
1
1.2
ppm TCE


CALIBRATION CURVE
20 Feb 98
Y = (1,812,361.4*X) + (-60,500)
GC Area
1000000
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
ppm TCE

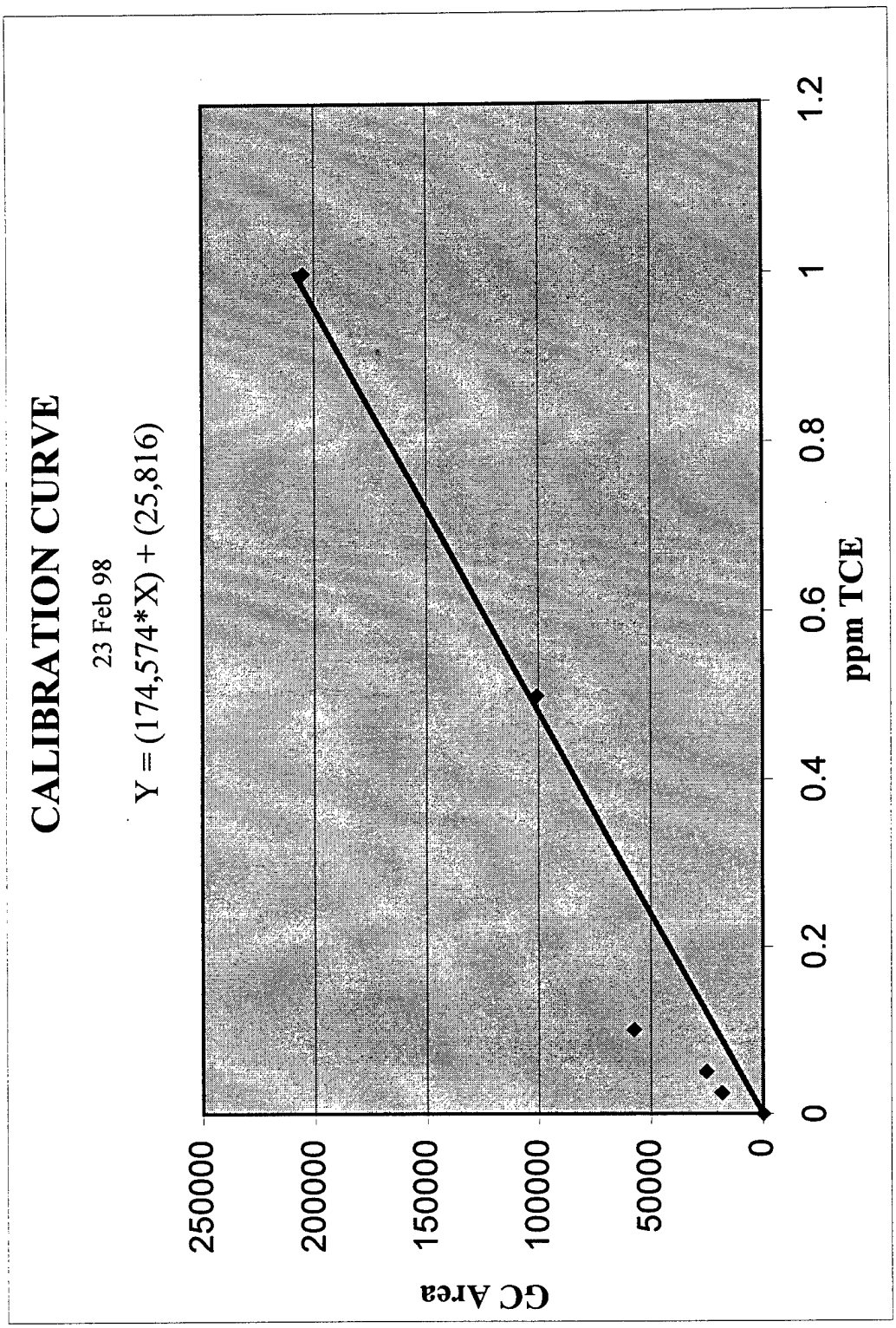

CALIBRATION CURVE
23 Feb 98
Y = (174,574*X) + (25,816)
GC Area
250000
200000
150000
100000
50000
0
0
0.2
0.4
0.6
0.8
1
1.2
ppm TCE

TABLE C-2.
Water and TCE Consumption Rates

Position → / Date ↓	1	2	3	4	5	6	7	8	9	10	11	12
	Chamber Number											
	9	**21**	**17**	**10**	**4**	**15**	**6**	**24**	**11**	**18**	**5**	**19**
Total Water (mL)	**1125**	**1340**	**1670**	**700**	**2225**	**1950**	**2250**	**1935**	**1000**	**2200**	**1775**	**990**
TCE (uL)	**21.5**	**3**	**34.5**	**14**	**44.5**	**39**	**44**	**6**	**20.5**	**44**	**34**	**0**
1-Jan-98												
Water (mL)	600				700		700				700	
TCE (uL)	11				14		13				13	
3-Jan-98												
Water (mL)	150				300		350				300	
TCE (uL)	3				6		7.5				5	
4-Jan-98												
Water (mL)		650	500	500	200	500	100	500	500	500	150	500
TCE (uL)			12	10	4	10	1.5		10.5	10	3.5	
5-Jan-98												
Water (mL)		150	300		25	300	300	400	100	400		
TCE (uL)			6		0.5	6	6		2	8		
6-Jan-98												
Water (mL)		100							100			
TCE (uL)									2			
8-Jan-98												
Water (mL)	25		275			200		300		300	100	40
TCE (uL)	0.5		5			4		6		6	2	
10-Jan-98												
Water (mL)					150	150	50				25	
TCE (uL)					3	3	1				0.5	
12-Jan-98												
Water (mL)		50	50				100			100	50	
TCE (uL)			1				2			2	1	
14-Jan-98												
Water (mL)		50	50									
TCE (uL)			1									
17-Jan-98												
Water (mL)	50		50		150	150	100	200	50	200	100	75
TCE (uL)	1		1		3	3	2		1	4	2	
20-Jan-98												
Water (mL)		50	100		100	100	100	75		100		50
TCE (uL)			2		2	2	2			2		
24-Jan-98												
Water (mL)	50	50	20	50	50	50		50	50	50	50	50
TCE (uL)	1			1	1	1			1	1	1	
26-Jan-98												
Water (mL)			50		50	50	50					50
TCE (uL)			1		1	1	1					

TABLE C-2. (Con't.)

Position → / Date ↓	1	2	3	4	5	6	7	8	9	10	11	12
	Chamber Number											
	9	**21**	**17**	**10**	**4**	**15**	**6**	**24**	**11**	**18**	**5**	**19**
30-Jan-98												
Water (mL)		150	100	50	150	150	150	100	50	150	150	25
TCE (uL)		3	2	1	3	3	3		1	3	3	
1-Feb-98												
Water (mL)	50			50								50
TCE (uL)	1			1								
4-Feb-98												
Water (mL)	50		50		150	150	100	200	50	200	100	75
TCE (uL)	1		1		3	3	2		1	4	2	
8-Feb-98												
Water (mL)		50	50		100	100	100	50		100		25
TCE (uL)			1		2	2	2			2		
11-Feb-98												
Water (mL)	150	40	75	50	100	50	50	60	100	100	50	50
TCE (uL)	3		1.5	1	2	1	1		2	2	1	

	Chamber Number											
TOTALS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Water (mL)	**2300**	**2350**	**1725**	**2225**	**1775**	**2250**	**1150**	**550**	**1125**	**700**	**1000**	**850**
TCE (uL)	**47.2**	**48**	**36.3**	**44.5**	**34**	**44**	**23**	**9**	**21.5**	**14**	**20.5**	**17**

TABLE C-2. (Con't.)

Position → / Date ↓	13	14	15	16	17	18	19	20	21	22	23	24
	Chamber Number											
	13	**14**	**20**	**2**	**23**	**3**	**7**	**16**	**22**	**8**	**1**	**12**
Total Water (mL)	**1625**	**1850**	**1550**	**2350**	**1675**	**1725**	**1150**	**1800**	**950**	**550**	**2300**	**850**
TCE (uL)	**32.5**	**36.7**	**4**	**48**	**0**	**36.3**	**23**	**36**	**0**	**9**	**47.2**	**17**
1-Jan-98												
Water (mL)				700		700	500			500	700	
TCE (uL)				15		15	9			8	15	
3-Jan-98												
Water (mL)				300		200	200				100	
TCE (uL)				6.5		4.3	5				2.2	
4-Jan-98												
Water (mL)	500	500	500	200	500	200		500	500		200	500
TCE (uL)	10	10		4.5		4.5		10			4	10
5-Jan-98												
Water (mL)	300	200			300			300				200
TCE (uL)	6	3.7						6				4
6-Jan-98												
Water (mL)		200				100		300			300	
TCE (uL)		4				2		6			6	
8-Jan-98												
Water (mL)	200	250	200		150							
TCE (uL)	4	5	4									
10-Jan-98												
Water (mL)		75	200	150	75						150	
TCE (uL)		1.5		2							3	
12-Jan-98												
Water (mL)				100				100			100	
TCE (uL)				2				2			2	
14-Jan-98												
Water (mL)												
TCE (uL)												
17-Jan-98												
Water (mL)	150	100	125	150	150	100	50	100	100		200	50
TCE (uL)	3	2		3		2	1	2			4	1
20-Jan-98												
Water (mL)	100	50	50	150	50	75		75				
TCE (uL)	2	1		3		1.5		1.5				
24-Jan-98												
Water (mL)		50	100	100	50	100	50	50			100	
TCE (uL)		1		2		2	1	1			2	
26-Jan-98												
Water (mL)				100	50	50	50	50				
TCE (uL)				2		1	1	1				

TABLE C-2. (Con't.)

Position → / Date ↓	13	14	15	16	17	18	19	20	21	22	23	24
	Chamber Number											
Date	**13**	**14**	**20**	**2**	**23**	**3**	**7**	**16**	**22**	**8**	**1**	**12**
30-Jan-98												
Water (mL)	100	100	100	150	50	50	100	100	100		150	
TCE (uL)	2	2		3		1	2	2			3	
1-Feb-98												
Water (mL)		75	50				50					50
TCE (uL)		1.5					1					1
4-Feb-98												
Water (mL)	150	100	125	150	150	100	50	100	100		200	50
TCE (uL)	3	2		3		2	1	2			4	1
8-Feb-98												
Water (mL)		50	50		100				150			
TCE (uL)		1										
11-Feb-98												
Water (mL)	125	100	50	100	50	50	100	125		50	100	
TCE (uL)	2.5	2		2		1	2	2.5		1	2	

	Chamber Number											
TOTALS	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Water (mL)	**1625**	**1850**	**1950**	**1800**	**1670**	**2200**	**990**	**1550**	**1340**	**950**	**1675**	**1935**
TCE (uL)	**32.5**	**36.7**	**39**	**36**	**34.5**	**44**	**0**	**4**	**3**	**0**	**0**	**6**

TABLE C-3.
Airflow Rates.

Position → / Date ↓	1	2	3	4	5	6	7	8	9	10	11	12
	Chamber Number											
	9	**21**	**17**	**10**	**4**	**15**	**6**	**24**	**11**	**18**	**5**	**19**
1-Jan-98												
Time (80 mL)	20.40				19.10		19.13				20.50	
Rate (L/min)	0.24				0.25		0.25				0.23	
5-Jan-98												
Time (80 mL)	15.90	20.40	19.70	16.00	17.00	26.00	15.60	27.00	26.00	22.00	16.00	24.00
Rate (L/min)	0.30	0.24	0.24	0.30	0.28	0.18	0.31	0.18	0.18	0.22	0.30	0.20
6-Jan-98												
Time (80 mL)	13.00	20.00	18.00	13.00	19.00	24.00	13.00	29.00	21.00	18.00	19.00	24.00
Rate (L/min)	0.37	0.24	0.27	0.37	0.25	0.20	0.37	0.17	0.23	0.27	0.25	0.20
8-Jan-98												
Time (80 mL)	13.00	20.90	16.00	10.80	15.00	21.50	9.00	31.00	22.40	16.00	10.30	27.10
Rate (L/min)	0.37	0.23	0.30	0.44	0.32	0.22	0.53	0.15	0.21	0.30	0.47	0.18
10-Jan-98												
Time (80 mL)	17.80	11.00	16.40	10.80	23.70	11.10	8.10	8.70	16.70	27.50	9.60	10.00
Rate (L/min)	0.27	0.44	0.29	0.44	0.20	0.43	0.59	0.55	0.29	0.17	0.50	0.48
12-Jan-98												
Time (80 mL)	12.50	8.00	10.00	16.50	27.50	10.40	9.90	10.00	29.30	30.10	11.90	10.30
Rate (L/min)	0.38	0.60	0.48	0.29	0.17	0.46	0.48	0.48	0.16	0.16	0.40	0.47
13-Jan-98												
Time (80 mL)	11.70	9.90	11.70	10.80	32.20	10.90	12.20	13.40	15.00	23.10	10.10	12.60
Rate (L/min)	0.41	0.48	0.41	0.44	0.15	0.44	0.39	0.36	0.32	0.21	0.48	0.38
14-Jan-98												
Time (80 mL)	10.30	10.30	11.20	10.60	30.10	10.80	14.70	12.90	13.30	27.40	16.90	13.90
Rate (L/min)	0.47	0.47	0.43	0.45	0.16	0.44	0.33	0.37	0.36	0.18	0.28	0.35
17-Jan-98												
Time (80 mL)	11.00	11.00	11.60	11.50	32.80	11.60	13.30	14.40	13.30	28.20	12.80	13.80
Rate (L/min)	0.44	0.44	0.41	0.42	0.15	0.41	0.36	0.33	0.36	0.17	0.38	0.35
20-Jan-98												
Time (80 mL)	11.80	8.20	9.80	10.30	34.80	10.80	11.60	13.90	12.40	29.70	11.30	12.60
Rate (L/min)	0.41	0.59	0.49	0.47	0.14	0.44	0.41	0.35	0.39	0.16	0.42	0.38
24-Jan-98												
Time (80 mL)	10.70	8.30	9.60	9.30	34.80	9.10	9.90	11.80	11.00	38.70	12.60	12.30
Rate (L/min)	0.45	0.58	0.50	0.52	0.14	0.53	0.48	0.41	0.44	0.12	0.38	0.39
26-Jan-98												
Time (80 mL)	11.50	9.20	9.50	9.60	25.80	9.70	11.10	13.20	11.40	35.20	10.70	14.00
Rate (L/min)	0.42	0.52	0.51	0.50	0.19	0.49	0.43	0.36	0.42	0.14	0.45	0.34
30-Jan-98												
Time (80 mL)	7.60	8.70	11.30	10.90	48.00	12.30	13.80	14.20	10.20	32.50	10.20	11.50
Rate (L/min)	0.63	0.55	0.42	0.44	0.10	0.39	0.35	0.34	0.47	0.15	0.47	0.42
1-Feb-98												
Time (80 mL)	10.60	8.30	12.30	11.90	29.60	12.20	10.40	12.80	12.10	22.40	11.90	12.90
Rate (L/min)	0.45	0.58	0.39	0.40	0.16	0.39	0.46	0.38	0.40	0.21	0.40	0.37

TABLE C-3. (Con't.)

Position → / Date ↓	1	2	3	4	5	6	7	8	9	10	11	12
	Chamber Number											
	9	**21**	**17**	**10**	**4**	**15**	**6**	**24**	**11**	**18**	**5**	**19**
4-Feb-98												
Time (80 mL)	10.30	8.60	10.70	10.60	31.30	12.10	14.50	14.20	10.30	34.00	10.40	11.70
Rate (L/min)	0.47	0.56	0.45	0.45	0.15	0.40	0.33	0.34	0.47	0.14	0.46	0.41
8-Feb-98												
Time (80 mL)	12.10	13.20	13.20	13.90	30.00	13.20	17.80	19.80	18.70	33.20	16.90	18.20
Rate (L/min)	0.40	0.36	0.36	0.35	0.16	0.36	0.27	0.24	0.26	0.14	0.28	0.26
11-Feb-98												
Time (80 mL)	8.20	9.90	10.90	8.90	22.40	12.30	10.00	11.60	11.60	40.80	11.10	11.90
Rate (L/min)	0.59	0.48	0.44	0.54	0.21	0.39	0.48	0.41	0.41	0.12	0.43	0.40
14-Feb-98												
Time (80 mL)	8.50	8.40	11.70	10.20	23.40	9.60	9.60	10.30	12.80	33.70	10.50	10.70
Rate (L/min)	0.56	0.57	0.41	0.47	0.21	0.50	0.50	0.47	0.38	0.14	0.46	0.45

** Broken Stem -- Unable to calculate flow rate

TABLE C-3. (Con't.)

Position → / Date ↓	13	14	15	16	17	18	19	20	21	22	23	24	
	Chamber Number												
	13	**14**	**20**	**2**	**23**	**3**	**7**	**16**	**22**	**8**	**1**	**12**	
1-Jan-98													
Time (80 mL)				24.80		27.98	19.13			24.40	25.23		**L/day**
Rate (L/min)				0.19		0.17	0.25			0.20	0.19		315.9
5-Jan-98													
Time (80 mL)	18.80	14.00	14.00	14.00	14.00	14.00	15.00	14.00	14.00	14.00	14.00	14.00	**L/day**
Rate (L/min)	0.26	0.34	0.34	0.34	0.34	0.34	0.32	0.34	0.34	0.34	0.34	0.34	416.4
6-Jan-98													
Time (80 mL)	18.40	12.00	12.00	14.00	15.40	22.00	18.00	18.90	21.40	19.70	24.00	14.00	**L/day**
Rate (L/min)	0.26	0.40	0.40	0.34	0.31	0.22	0.27	0.25	0.22	0.24	0.20	0.34	398.7
8-Jan-98													
Time (80 mL)	17.00	10.60	12.60	12.00	18.20	8.40	18.20	8.40	25.50	20.20	9.10	20.70	**L/day**
Rate (L/min)	0.28	0.45	0.38	0.40	0.26	0.57	0.26	0.57	0.19	0.24	0.53	0.23	486.2
10-Jan-98													
Time (80 mL)	17.70	11.00	17.90	*	8.00	10.70	20.50	12.60	10.60	9.20	8.90	9.90	**L/day**
Rate (L/min)	0.27	0.44	0.27		0.60	0.45	0.23	0.38	0.45	0.52	0.54	0.48	582.4
12-Jan-98													
Time (80 mL)	33.20	13.40	31.20	*	10.30	10.10	10.70	14.80	13.00	10.40	10.50	12.00	**L/day**
Rate (L/min)	0.14	0.36	0.15		0.47	0.48	0.45	0.32	0.37	0.46	0.46	0.40	538.9
13-Jan-98													
Time (80 mL)	13.60	11.20	13.80	*	12.10	10.90	13.80	12.30	14.90	12.50	13.50	14.00	**L/day**
Rate (L/min)	0.35	0.43	0.35		0.40	0.44	0.35	0.39	0.32	0.38	0.36	0.34	537.4
14-Jan-98													
Time (80 mL)	13.20	12.00	15.50	*	12.70	11.70	14.50	12.40	13.30	12.60	19.00	14.80	**L/day**
Rate (L/min)	0.36	0.40	0.31		0.38	0.41	0.33	0.39	0.36	0.38	0.25	0.32	512.1
17-Jan-98													
Time (80 mL)	13.50	11.00	13.20	*	12.80	15.30	14.70	14.00	17.40	12.40	14.00	13.20	**L/day**
Rate (L/min)	0.36	0.44	0.36		0.38	0.31	0.33	0.34	0.28	0.39	0.34	0.36	506.8
20-Jan-98													
Time (80 mL)	11.90	10.80	11.30	*	10.00	13.10	13.50	11.90	12.80	12.70	15.50	13.50	**L/day**
Rate (L/min)	0.40	0.44	0.42		0.48	0.37	0.36	0.40	0.38	0.38	0.31	0.36	559.7
24-Jan-98													
Time (80 mL)	11.00	9.70	12.30	*	10.20	15.10	12.30	14.30	15.00	11.40	11.40	12.40	**L/day**
Rate (L/min)	0.44	0.49	0.39		0.47	0.32	0.39	0.34	0.32	0.42	0.42	0.39	583.3
26-Jan-98													
Time (80 mL)	11.50	9.80	12.20	*	10.20	10.60	12.90	13.60	11.10	11.00	11.50	12.50	**L/day**
Rate (L/min)	0.42	0.49	0.39		0.47	0.45	0.37	0.35	0.43	0.44	0.42	0.38	587.9
30-Jan-98													
Time (80 mL)	12.60	10.50	16.60	*	10.40	14.50	10.30	13.00	13.30	10.40	13.60	10.40	**L/day**
Rate (L/min)	0.38	0.46	0.29		0.46	0.33	0.47	0.37	0.36	0.46	0.35	0.46	571.2
1-Feb-98													
Time (80 mL)	14.30	11.30	12.90	*	11.60	11.50	12.30	11.60	15.60	11.60	12.90	13.20	**L/day**
Rate (L/min)	0.34	0.42	0.37		0.41	0.42	0.39	0.41	0.31	0.41	0.37	0.36	552.7

TABLE C-3. (Con't.)

Position → / Date ↓	13	14	15	16	17	18	19	20	21	22	23	24	
	Chamber Number												
	13	**14**	**20**	**2**	**23**	**3**	**7**	**16**	**22**	**8**	**1**	**12**	
4-Feb-98													
Time (80 mL)	12.30	12.60	13.90	*	9.80	10.60	11.30	13.60	13.80	9.80	12.00	11.40	**L/day**
Rate (L/min)	0.39	0.38	0.35		0.49	0.45	0.42	0.35	0.35	0.49	0.40	0.42	570.9
8-Feb-98													
Time (80 mL)	18.90	17.10	21.50	*	11.30	28.60	11.20	10.10	13.30	11.50	12.30	11.70	**L/day**
Rate (L/min)	0.25	0.28	0.22		0.42	0.17	0.43	0.48	0.36	0.42	0.39	0.41	456.2
11-Feb-98													
Time (80 mL)	12.00	11.30	13.70	*	11.70	13.10	11.30	9.20	13.60	10.50	11.30	11.80	**L/day**
Rate (L/min)	0.40	0.42	0.35		0.41	0.37	0.42	0.52	0.35	0.46	0.42	0.41	592.0
14-Feb-98													
Time (80 mL)	12.40	9.30	12.40	*	11.70	10.20	10.10	11.10	13.60	12.00	11.00	12.10	**L/day**
Rate (L/min)	0.39	0.52	0.39		0.41	0.47	0.48	0.43	0.35	0.40	0.44	0.40	612.1

** Broken Stem -- Unable to calculate flow rate

TABLE C-4.
Recovered TCE

Total Water Added in mL				
Plant Type	**Mean**	**Std. Dev.**	**Low**	**High**
Alfalfa	1994	282	1711	2276
Soil	965	190	775	1155
BG w/TCE	1849	209	1640	2058
BG w/o TCE	1205	408	797	1613

Total TCE Added in ug				
Plant Type	**Mean**	**Std. Dev.**	**Low**	**High**
Alfalfa	55580	7477	48103	63057
Soil	26880	5110	21770	31990
BG w/TCE	51963	5618	46346	57581
BG w/o TCE	0	0	0	0

Recovered TCE (ug) From Air				
Plant Type	**Mean**	**Std. Dev.**	**Low**	**High**
Alfalfa	1140	294	846	1434
Soil	1542	549	993	2092
BG w/TCE	1395	285	1109	1680
BG w/o TCE	34	16	18	50

Recovered TCE (ug) From Soil				
Plant Type	**Mean**	**Std. Dev.**	**Low**	**High**
Alfalfa	122	60	62	182
Soil	135	72	63	207
BG w/TCE	102	43	59	145
BG w/o TCE	0	0	0	0

Recovered TCE (ug) From Water				
Plant Type	**Mean**	**Std. Dev.**	**Low**	**High**
Alfalfa	436	256	179	692
Soil	628	179	449	808
BG w/TCE	641	193	448	833
BG w/o TCE	0	0	0	0

TABLE C-5.
Sample Analysis Results

	Alfalfa						Soil					
Chamber No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	→											
Water (mL)	**2300**	**2350**	**1725**	**2225**	**1775**	**2250**	**1150**	**550**	**1125**	**700**	**1000**	**850**
TCE (uL)	**47.2**	**48**	**36.3**	**44.5**	**34**	**44**	**23**	**9**	**21.5**	**14**	**20.5**	**17**
TCE (ug)	66,080	67,200	50,820	62,300	47,600	61,600	32,200	12,600	30,100	19,600	28,700	23,800
Air (ug)	1540	2,604	1,347	960	823	1,429	1,692	796	1,392	2,312	1,527	789
Water (ug)	6	0	90	625	394	635	821	149	482	754	402	682
Soil (ug)	0	0	59	204	115	110	192	0	87	229	103	63
Plant (ug)	0	0	0	0	0	0	0				0	
Total TCE (ug)	**1545**	**2604**	**1496**	**1789**	**1332**	**2175**	**2706**	**944**	**1962**	**3296**	**2032**	**1534**
	Raw Sample Data						Raw Sample Data					
Sand (ug/kg)	0	0	0	81.4	3.6	5.4	6.1	0	3	4.2	2.6	3.7
Gravel (ug/kg)	0	0	3.6	8	11.9	6.5	17.6	0	5.1	56.7	7	9
Soil (ug/kg)	0	0	18	30.6	31	31.5	53.1	0	25.5	46.4	30	15
Plant (ug)	0	0	0	0	0	0	0				0	
Water (ug/L)	11.5	0	179.1	1250.2	787.1	1270.9	1642.9	297	963.9	1508.6	803.8	1364.2

TABLE C-5. (Con't.)

	BG - w/TCE						BG - w/o TCE					
Chamber No.	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
→	→											
Water (mL)	**1625**	**1850**	**1950**	**1800**	**1670**	**2200**	**990**	**1550**	**1340**	**950**	**1675**	**1935**
TCE (uL)	**32.5**	**36.7**	**39**	**36**	**34.5**	**44**	**0**	**4**	**3**	**0**	**0**	**6**
TCE (ug)	45,500	51,380	54,600	50,400	48,300	61,600	0	5,600	4,200	0	0	8,400
Air (ug)	1,593	1,547	1,129	1,279	1,771	1,049	33	314	761	50	19	637
Water (ug)	489	545	902	864	462	582	0	21	258	0	0	91
Soil (ug)	47	79	91	175	116	105	0	24	52	0	0	5
Plant (ug)	0	0	0	0	0	0	0	0	0	0	0	0
Total TCE (ug)	**2129**	**2170**	**2123**	**2317**	**2349**	**1736**	**33**	**359**	**1071**	**50**	**19**	**732**
	Raw Sample Data						Raw Sample Data					
Sand (ug/kg)	4.1	2.2	3	4.1	3.5	16.4	0	0	10.8	0	0	3.7
Gravel (ug/kg)	13.2	10.9	4	26.8	9.6	11.3	0	0	9.5	0	0	0
Soil (ug/kg)	7.2	20.1	27.4	43.3	32.6	22.7	0	8.1	8.2	0	0	0
Plant (ug)	0	0	0	0	0	0	0	0	0	0	0	0
Water (ug/L)	978	1089.8	1804.9	1727	924.8	1163.7	0	42.3	516.3	0	0	181.2

APPENDIX D

SAMPLE LOG

The sample log provides an overview of the total cost for the analysis and each sample result for the entire experiment. Detailed information on air sample breakthrough is also provided in this appendix.

Contents:

TABLE D-1.
Sample Log

Sampling Budget:	Starting	Used	Total Spent
	$6,000	$8,850	$58,548

Sample	Air	Soil	Water	Veg
Cost	$47,698	$6,375	$2,475	$2,000

Sample No.	Type of Sample	Chambe No.	Collection Date	Lab Rec'd Date	Temp at Lab	Analysis Date	Results TCE	DCE	VC	CT	Cost	Comments	Air In/Out	B-T >10%
FX 988001	Air	1	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	BDL	BDL	$206		in	
FX 988002	Air	2	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	BDL	BDL	$206		in	
FX 988003	Air	3	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	BDL	BDL	$206		in	
FX 988004	Air	4	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	BDL	BDL	$206	BDL -- Below Detection Limit	in	
FX 988005	Air	5	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	BDL	BDL	$206		in	
FX 988006	Air	6	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	BDL	BDL	$206		in	
FX 988007	Air	7	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	BDL	BDL	$206		in	
FX 988008	Air	8	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	BDL	BDL	$206		in	
FX 988009	Air	9	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	BDL	BDL	$206	Background samples	in	
FX 988010	Air	1	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	7.2	BDL	$206	after running for 12 hours.	out	
FX 988011	Air	2	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	BDL	BDL	$206		out	
FX 988012	Air	3	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	6.5	BDL	$206		out	
FX 988013	Air	4	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	BDL	BDL	$206		out	
FX 988014	Air	5	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	BDL	BDL	$206	**TCE Detection Limit: 1.2 ug**	out	
FX 988015	Air	6	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	BDL	BDL	$206	**DCE Detection Limit: 0.4 ug**	out	
FX 988016	Air	7	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	7	BDL	$206	**VC Detection Limit: 1.7 ug**	out	
FX 988017	Air	8	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	6.3	BDL	$206	**CT Detection Limit: 6.3 ug**	out	
FX 988018	Air	9	1-Jan-98	2-Jan-98	Room	8-Jan-98	BDL	BDL	BDL	BDL	$206		out	
GS 988019	Soil	BG	1-Jan-98	2-Jan-98	6	12-Jan-98	20	20	20	20	$75		in	
GS 988020	Soil	BG	1-Jan-98	2-Jan-98	6	12-Jan-98	20	20	20	20	$75	**Soil results are in ug/kg**	in	
GS 988021	Soil	BG	1-Jan-98	2-Jan-98	6	12-Jan-98	10900	20	20	20	$75	**Water results are in ug/L**	in	
GS 988022	Soil	BG	1-Jan-98	2-Jan-98	6	12-Jan-98	20	20	20	20	$75		in	
GS 988023	Soil	BG	1-Jan-98	2-Jan-98	6	12-Jan-98	20	20	20	20	$75		in	
GN 988024	Water	BG	1-Jan-98	2-Jan-98	6	12-Jan-98	388.5	10	10	10	$75		in	
GN 988025	Water	BG	1-Jan-98	2-Jan-98	6	12-Jan-98	12.6	5	5	5	$75		in	
GN 988026	Water	BG	1-Jan-98	2-Jan-98	6	12-Jan-98	261	5	5	5	$75		in	
FX 988027	Air	9	14-Jan-98	15-Jan-98	Room	22-Jan-98	116.7	ND	ND	675.1	$206		out	y
FX 988028	Air	9	14-Jan-98	15-Jan-98	Room	22-Jan-98	15.4	3.3	ND	880.6	$206	ND - Non-detect at Detection Limits	in	
FX 988029	Air	21	14-Jan-98	15-Jan-98	Room	22-Jan-98	258.4	ND	ND	188	$206		out	y
FX 988030	Air	21	14-Jan-98	15-Jan-98	Room	22-Jan-98	31.1	4.6	ND	1243.9	$206	**Pump on @ 1145; 3 Jan 98**	in	
FX 988031	Air	17	14-Jan-98	15-Jan-98	Room	22-Jan-98	16.3	3.3	ND	849.7	$206	**Pump off on 14 Jan 98 @ 1115**	in	
FX 988032	Air	17	14-Jan-98	15-Jan-98	Room	22-Jan-98	708	ND	ND	413.2	$206		out	y
FX 988033	Air	10	14-Jan-98	15-Jan-98	Room	22-Jan-98	27.2	4.2	ND	1169.6	$206		in	
FX 988034	Air	10	14-Jan-98	15-Jan-98	Room	22-Jan-98	100.3	ND	ND	460.2	$206		out	y
FX 988035	Air	4	14-Jan-98	15-Jan-98	Room	22-Jan-98	250	ND	ND	684	$206		out	y

TABLE D-1. (Con't.)

Sample No.	Type of Sample	Chambe No.	Collection Date	Lab Rec'd Date	Temp at Lab	Analysis Date	Results				Cost	Comments	Air In/Out	B-T >10%
							TCE	DCE	VC	CT				
FX 988036	Air	4	14-Jan-98	15-Jan-98	Room	22-Jan-98	14.4	2.2	ND	585.3	$206		in	
FX 988037	Air	15	14-Jan-98	15-Jan-98	Room	22-Jan-98	42.9	3.7	ND	1197	$206		in	
FX 988038	Air	15	14-Jan-98	15-Jan-98	Room	22-Jan-98	331	ND	ND	199.1	$206		out	y
FX 988039	Air	6	14-Jan-98	15-Jan-98	Room	22-Jan-98	32.6	1.7	ND	1062.9	$206		in	
FX 988040	Air	6	14-Jan-98	15-Jan-98	Room	22-Jan-98	686	ND	ND	288.4	$206		out	y
FX 988041	Air	24	14-Jan-98	15-Jan-98	Room	22-Jan-98	35.6	4.3	ND	1307	$206		in	
FX 988042	Air	24	14-Jan-98	15-Jan-98	Room	22-Jan-98	408	ND	ND	150.4	$206		out	y
FX 988043	Air	11	14-Jan-98	15-Jan-98	Room	22-Jan-98	16.2	3.3	ND	709.9	$206		in	
FX 988044	Air	11	14-Jan-98	15-Jan-98	Room	22-Jan-98	145.6	ND	ND	560.2	$206		out	y
FX 988045	Air	18	14-Jan-98	15-Jan-98	Room	22-Jan-98	18.7	2	ND	693.4	$206		in	
FX 988046	Air	18	14-Jan-98	15-Jan-98	Room	22-Jan-98	326	ND	ND	479	$206		out	y
FX 988047	Air	5	14-Jan-98	15-Jan-98	Room	22-Jan-98	299	ND	ND	109.7	$206		out	y
FX 988048	Air	5	14-Jan-98	15-Jan-98	Room	22-Jan-98	50.1	4.6	ND	1849	$206		in	
FX 988049	Air	19	14-Jan-98	15-Jan-98	Room	22-Jan-98	8.8	ND	ND	390.6	$206		out	y
FX 988050	Air	19	14-Jan-98	15-Jan-98	Room	22-Jan-98	38.6	3.7	ND	1212	$206		in	
FX 988051	Air	13	14-Jan-98	15-Jan-98	Room	22-Jan-98	757	ND	ND	401.3	$206		out	y
FX 988052	Air	13	14-Jan-98	15-Jan-98	Room	22-Jan-98	17.5	3.4	ND	847.3	$206		in	
FX 988053	Air	14	14-Jan-98	15-Jan-98	Room	22-Jan-98	559	ND	ND	217.1	$206		out	y
FX 988054	Air	14	14-Jan-98	15-Jan-98	Room	22-Jan-98	312	2.7	ND	1384	$206		in	
FX 988055	Air	20	14-Jan-98	15-Jan-98	Room	22-Jan-98	257.4	ND	ND	260.8	$206		out	y
FX 988056	Air	20	14-Jan-98	15-Jan-98	Room	22-Jan-98	19.8	3.5	ND	1053	$206		in	
FX 988057	Air	2	14-Jan-98	15-Jan-98	Room	22-Jan-98	276	ND	ND	316	$206		out	y
FX 988058	Air	2	14-Jan-98	15-Jan-98	Room	22-Jan-98	BIT	BIT	BIT	BIT	$206		in	
FX 988059	Air	23	14-Jan-98	15-Jan-98	Room	22-Jan-98	10.9	ND	ND	372.4	$206		out	y
FX 988060	Air	23	14-Jan-98	15-Jan-98	Room	22-Jan-98	35	3.9	ND	1147.7	$206		in	
FX 988061	Air	3	14-Jan-98	15-Jan-98	Room	22-Jan-98	441	ND	ND	209.8	$206		out	y
FX 988062	Air	3	14-Jan-98	15-Jan-98	Room	22-Jan-98	35.2	3.8	ND	1474	$206		in	
FX 988063	Air	7	14-Jan-98	15-Jan-98	Room	22-Jan-98	596	ND	ND	420.1	$206		out	y
FX 988064	Air	7	14-Jan-98	15-Jan-98	Room	22-Jan-98	37.4	3.6	ND	1236	$206		in	
FX 988065	Air	16	14-Jan-98	15-Jan-98	Room	22-Jan-98	654	ND	ND	339	$206		out	y
FX 988066	Air	16	14-Jan-98	15-Jan-98	Room	22-Jan-98	34.1	4	ND	1411	$206		in	
FX 988067	Air	22	14-Jan-98	15-Jan-98	Room	22-Jan-98	17.8	ND	ND	626	$206		out	y
FX 988068	Air	22	14-Jan-98	15-Jan-98	Room	22-Jan-98	33.9	4	ND	1214.3	$206		in	
FX 988069	Air	8	14-Jan-98	15-Jan-98	Room	22-Jan-98	527	ND	ND	419	$206		out	y
FX 988070	Air	8	14-Jan-98	15-Jan-98	Room	22-Jan-98	35.6	3.4	ND	1104.8	$206		in	
FX 988071	Air	1	14-Jan-98	15-Jan-98	Room	22-Jan-98	906	ND	ND	361.5	$206		out	y
FX 988072	Air	1	14-Jan-98	15-Jan-98	Room	22-Jan-98	59.4	3.6	ND	1175	$206		in	y
FX 988073	Air	12	14-Jan-98	15-Jan-98	Room	22-Jan-98	129.8	ND	ND	408.9	$206		out	y
FX 988074	Air	12	14-Jan-98	15-Jan-98	Room	22-Jan-98	35.7	4.5	ND	1093.7	$206		in	

TABLE D-1. (Con't.)

Sample No.	Type of Sample	Chambe No.	Collection Date	Lab Rec'd Date	Temp at Lab	Analysis Date	Results				Cost	Comments	Air In/Out	B-T >10%
							TCE	DCE	VC	CT				
FX 988075	Air	2	14-Jan-98	15-Jan-98	Room	22-Jan-98	1959	ND	ND	157.8	$206		out	y
FX 988076	Air	9	27-Jan-98	28-Jan-98	Room	04-Feb-98	251.8	ND	ND	1054	$206		out	y
FX 988077	Air	21	27-Jan-98	28-Jan-98	Room	04-Feb-98	142.7	ND	ND	240.5	$206		out	y
FX 988078	Air	17	27-Jan-98	28-Jan-98	Room	04-Feb-98	386	ND	ND	289.9	$206		out	y
FX 988079	Air	10	27-Jan-98	28-Jan-98	Room	04-Feb-98	550	ND	ND	462.7	$206		out	y
FX 988080	Air	4	27-Jan-98	28-Jan-98	Room	04-Feb-98	153.6	ND	ND	499	$206		out	y
FX 988081	Air	15	27-Jan-98	28-Jan-98	Room	04-Feb-98	245.3	ND	ND	264.9	$206		out	y
FX 988082	Air	6	27-Jan-98	28-Jan-98	Room	04-Feb-98	239.1	ND	ND	315.6	$206		out	y
FX 988083	Air	24	27-Jan-98	28-Jan-98	Room	04-Feb-98	119.5	ND	ND	18.9	$206		out	y
FX 988084	Air	11	27-Jan-98	28-Jan-98	Room	04-Feb-98	429	ND	ND	539.7	$206		out	y
FX 988085	Air	18	27-Jan-98	28-Jan-98	Room	04-Feb-98	103.1	ND	ND	375	$206	All of this samples are the effluent filters	out	y
FX 988086	Air	5	27-Jan-98	28-Jan-98	Room	04-Feb-98	145.7	ND	ND	213.8	$206	(out)	out	y
FX 988087	Air	19	27-Jan-98	28-Jan-98	Room	04-Feb-98	11.8	ND	ND	346	$206		out	y
FX 988088	Air	13	27-Jan-98	28-Jan-98	Room	04-Feb-98	255.4	ND	ND	372	$206		out	y
FX 988089	Air	14	27-Jan-98	28-Jan-98	Room	04-Feb-98	314	ND	ND	155.7	$206		out	y
FX 988090	Air	20	27-Jan-98	28-Jan-98	Room	04-Feb-98	33.5	ND	ND	213.2	$206		out	y
FX 988091	Air	2	27-Jan-98	28-Jan-98	Room	04-Feb-98	129.4	ND	ND	63.1	$206		out	y
FX 988092	Air	23	27-Jan-98	28-Jan-98	Room	04-Feb-98	ND	ND	ND	272.9	$206		out	y
FX 988093	Air	3	27-Jan-98	28-Jan-98	Room	04-Feb-98	192.6	ND	ND	94.1	$206		out	y
FX 988094	Air	7	27-Jan-98	28-Jan-98	Room	04-Feb-98	596	ND	ND	412.4	$206		out	y
FX 988095	Air	16	27-Jan-98	28-Jan-98	Room	04-Feb-98	240.9	ND	ND	100	$206		out	y
FX 988096	Air	22	27-Jan-98	28-Jan-98	Room	04-Feb-98	ND	ND	ND	444.8	$206		out	y
FX 988097	Air	8	27-Jan-98	28-Jan-98	Room	04-Feb-98	61.8	ND	ND	297.2	$206	**Pump on @ 1205; 14 Jan 98**	out	y
FX 988098	Air	1	27-Jan-98	28-Jan-98	Room	04-Feb-98	280	ND	ND	251.3	$206	**Pump off @ 6 am 27 Jan 98 due to circuit breaker**	out	y
FX 988099	Air	12	27-Jan-98	28-Jan-98	Room	04-Feb-98	175.2	ND	ND	255.1	$206		out	y
FX 988100	Air	Blank	27-Jan-98	28-Jan-98	Room	04-Feb-98	ND	ND	ND	ND	$206	Blank - ran water through tube.	b	
FX 988101	Air	Blank	8-Feb-98	13-Feb-98	Room	23-Feb-98	ND	ND	ND	ND	$206		in	
FX 988102	Air	9	8-Feb-98	13-Feb-98	Room	23-Feb-98	127	ND	ND	1682.9	$206	**Pump on @ 12:00 27 Jan 98**	in	
FX 988103	Air	21	8-Feb-98	13-Feb-98	Room	23-Feb-98	190	ND	ND	2302	$206	**Pump off @ 16:00 8 Feb 98**	in	
FX 988104	Air	17	8-Feb-98	13-Feb-98	Room	23-Feb-98	150	ND	ND	1933	$206		in	
FX 988105	Air	10	8-Feb-98	13-Feb-98	Room	23-Feb-98	150	ND	ND	1895.6	$206		in	
FX 988106	Air	Blank	8-Feb-98	13-Feb-98	Room	23-Feb-98	ND	ND	ND	ND	$206	(In Samples)	in	
FX 988107	Air	4	8-Feb-98	13-Feb-98	Room	23-Feb-98	12.5	ND	ND	926	$206		in	
FX 988108	Air	15	8-Feb-98	13-Feb-98	Room	23-Feb-98	49.2	ND	ND	2004	$206		in	
FX 988109	Air	6	8-Feb-98	13-Feb-98	Room	23-Feb-98	49.7	ND	ND	2084.3	$206		in	
FX 988110	Air	24	8-Feb-98	13-Feb-98	Room	23-Feb-98	55.4	ND	ND	2134.9	$206		in	
FX 988111	Air	11	8-Feb-98	13-Feb-98	Room	23-Feb-98	69.4	ND	ND	2427	$206		in	
FX 988112	Air	18	8-Feb-98	13-Feb-98	Room	23-Feb-98	17.1	ND	ND	960.6	$206		in	
FX 988113	Air	5	8-Feb-98	13-Feb-98	Room	23-Feb-98	55.7	ND	ND	2024.3	$206		in	

TABLE D-1. (Con't.)

Sample No.	Type of Sample	Chambe No.	Collection Date	Lab Rec'd Date	Temp at Lab	Analysis Date	Results				Cost	Comments	Air In/Out	B-T >10%
							TCE	DCE	VC	CT				
FX 988114	Air	19	8-Feb-98	13-Feb-98	Room	23-Feb-98	51.5	ND	ND	1948.5	$206		in	
FX 988115	Air	Blank	8-Feb-98	13-Feb-98	Room	23-Feb-98	ND	ND	ND	ND	$206		in	
FX 988116	Air	13	8-Feb-98	13-Feb-98	Room	23-Feb-98	27.5	13.4	ND	1938.2	$206		in	
FX 988117	Air	14	8-Feb-98	13-Feb-98	Room	23-Feb-98	37.5	ND	ND	3490.4	$206		in	
FX 988118	Air	20	8-Feb-98	13-Feb-98	Room	23-Feb-98	30.8	14.3	ND	2758.4	$206		in	
FX 988119	Air	2	8-Feb-98	13-Feb-98	Room	23-Feb-98	3.9	7.8	ND	110	$206		in	
FX 988120	Air	23	8-Feb-98	13-Feb-98	Room	23-Feb-98	32.5	13.6	ND	2228.2	$206		in	
FX 988121	Air	3	8-Feb-98	13-Feb-98	Room	23-Feb-98	27.8	13.7	ND	2473.3	$206		in	
FX 988122	Air	Blank	8-Feb-98	13-Feb-98	Room	23-Feb-98	ND	ND	ND	ND	$206		in	
FX 988123	Air	7	8-Feb-98	13-Feb-98	Room	23-Feb-98	26.2	13.6	ND	1998.1	$206		in	
FX 988124	Air	16	8-Feb-98	13-Feb-98	Room	23-Feb-98	27.1	13.9	ND	2648.4	$206		in	
FX 988125	Air	22	8-Feb-98	13-Feb-98	Room	23-Feb-98	24.5	13.7	ND	2022	$206		in	
FX 988126	Air	8	8-Feb-98	13-Feb-98	Room	23-Feb-98	29.3	14.6	ND	2616.8	$206		in	
FX 988127	Air	1	8-Feb-98	13-Feb-98	Room	23-Feb-98	31	16.3	ND	199.8	$206		in	
FX 988128	Air	12	8-Feb-98	13-Feb-98	Room	23-Feb-98	37.2	18.6	ND	234.1	$206		in	
FX 988129	Air	9	8-Feb-98	13-Feb-98	Room	23-Feb-98	454	3.4	ND	1537	$206		out	y
FX 988130	Air	21	8-Feb-98	13-Feb-98	Room	23-Feb-98	145.4	ND	ND	282.4	$206		out	y
FX 988131	Air	17	8-Feb-98	13-Feb-98	Room	23-Feb-98	257	ND	ND	716	$206		out	y
FX 988132	Air	10	8-Feb-98	13-Feb-98	Room	23-Feb-98	879	7.3	ND	668	$206		out	y
FX 988133	Air	4	8-Feb-98	13-Feb-98	Room	23-Feb-98	152.6	ND	ND	623	$206		out	y
FX 988134	Air	15	8-Feb-98	13-Feb-98	Room	23-Feb-98	181.6	ND	ND	353.9	$206		out	y
FX 988135	Air	6	8-Feb-98	13-Feb-98	Room	23-Feb-98	176	ND	ND	253.1	$206	(Out Samples)	out	y
FX 988136	Air	24	8-Feb-98	13-Feb-98	Room	23-Feb-98	63	ND	ND	38.6	$206		out	y
FX 988137	Air	11	8-Feb-98	13-Feb-98	Room	23-Feb-98	392	ND	ND	493	$206		out	y
FX 988138	Air	18	8-Feb-98	13-Feb-98	Room	23-Feb-98	135.7	ND	ND	565	$206		out	y
FX 988139	Air	5	8-Feb-98	13-Feb-98	Room	23-Feb-98	173.2	ND	ND	429	$206		out	y
FX 988140	Air	19	8-Feb-98	13-Feb-98	Room	23-Feb-98	10.5	ND	ND	465	$206		out	y
FX 988141	Air	13	8-Feb-98	13-Feb-98	Room	23-Feb-98	288	ND	ND	719	$206		out	y
FX 988142	Air	14	8-Feb-98	13-Feb-98	Room	23-Feb-98	260.7	ND	ND	230.4	$206		out	y
FX 988143	Air	20	8-Feb-98	13-Feb-98	Room	23-Feb-98	17.7	ND	ND	264.6	$206		out	y
FX 988144	Air	2	8-Feb-98	13-Feb-98	Room	23-Feb-98	34.7	ND	ND	61	$206		out	y
FX 988145	Air	23	8-Feb-98	13-Feb-98	Room	23-Feb-98	7.9	ND	ND	267.3	$206		out	y
FX 988146	Air	3	8-Feb-98	13-Feb-98	Room	23-Feb-98	282.9	ND	ND	493.6	$206		out	y
FX 988147	Air	7	8-Feb-98	13-Feb-98	Room	23-Feb-98	187.5	ND	ND	159.8	$206		out	y
FX 988148	Air	16	8-Feb-98	13-Feb-98	Room	23-Feb-98	ND	ND	ND	ND	$206		out	
FX 988149	Air	22	8-Feb-98	13-Feb-98	Room	23-Feb-98	16.3	ND	ND	818.9	$206		out	y
FX 988150	Air	8	8-Feb-98	13-Feb-98	Room	23-Feb-98	154.8	ND	ND	300.9	$206		out	y
FX 988151	Air	1	8-Feb-98	13-Feb-98	Room	23-Feb-98	187.8	ND	ND	238.9	$206		out	y
FX 988152	Air	12	8-Feb-98	13-Feb-98	Room	23-Feb-98	251.1	ND	ND	249.3	$206		out	y

TABLE D-1. (Con't.)

Sample No.	Type of Sample	Chambe No.	Collection Date	Lab Rec'd Date	Temp at Lab	Analysis Date	Results				Cost	Comments	Air In/Out	B-T >10%
							TCE	DCE	VC	CT				
FX 988153	Air	Blank	8-Feb-98	13-Feb-98	Room	23-Feb-98	ND	ND	ND	ND	$206		b	
FX 988154	Air	9	11-Feb-98	13-Feb-98	Room	23-Feb-98	190.9	ND	ND	574.8	$206	Used for calibration	out	y
FX 988155	Air	21	11-Feb-98	13-Feb-98	Room	23-Feb-98	123	ND	ND	196.9	$206		out	y
FX 988156	Air	17	11-Feb-98	13-Feb-98	Room	23-Feb-98	239.4	ND	ND	385.2	$206		out	y
FX 988157	Air	10	11-Feb-98	13-Feb-98	Room	23-Feb-98	256.2	ND	ND	625	$206		out	y
FX 988158	Air	Blank	11-Feb-98	13-Feb-98	Room	23-Feb-98	ND	ND	ND	ND	$206	**Pump on @ 17:00 8 Feb 98**	b	
FX 988159	Air	4	11-Feb-98	13-Feb-98	Room	23-Feb-98	203.8	ND	ND	437	$206	**Pump off @ 11:30 11 Feb 98**	out	y
FX 988160	Air	15	11-Feb-98	13-Feb-98	Room	23-Feb-98	214.2	ND	ND	216	$206		out	y
FX 988161	Air	6	11-Feb-98	13-Feb-98	Room	23-Feb-98	208.7	ND	ND	234.6	$206		out	y
FX 988162	Air	24	11-Feb-98	13-Feb-98	Room	23-Feb-98	20.4	ND	ND	141.1	$206		out	y
FX 988163	Air	11	11-Feb-98	13-Feb-98	Room	23-Feb-98	226.4	ND	ND	286.5	$206		out	y
FX 988164	Air	18	11-Feb-98	13-Feb-98	Room	23-Feb-98	301	ND	ND	430	$206		out	y
FX 988165	Air	Blank	11-Feb-98	13-Feb-98	Room	23-Feb-98	ND	ND	ND	ND	$206		b	
FX 988166	Air	5	11-Feb-98	13-Feb-98	Room	23-Feb-98	95.1	ND	ND	289.6	$206		out	y
FX 988167	Air	19	11-Feb-98	13-Feb-98	Room	23-Feb-98	1.9	ND	ND	240.2	$206		out	y
FX 988168	Air	13	11-Feb-98	13-Feb-98	Room	23-Feb-98	115.9	ND	ND	249.2	$206		out	y
FX 988169	Air	14	11-Feb-98	13-Feb-98	Room	23-Feb-98	219.1	ND	ND	107	$206		out	y
FX 988170	Air	20	11-Feb-98	13-Feb-98	Room	23-Feb-98	2.5	ND	ND	138	$206		out	y
FX 988171	Air	2	11-Feb-98	13-Feb-98	Room	23-Feb-98	98.7	ND	ND	49.9	$206		out	y
FX 988172	Air	23	11-Feb-98	13-Feb-98	Room	23-Feb-98	ND	ND	ND	154	$206		out	
FX 988173	Air	Blank	11-Feb-98	13-Feb-98	Room	23-Feb-98	ND	ND	ND	ND	$206		b	
FX 988174	Air	3	11-Feb-98	13-Feb-98	Room	23-Feb-98	223.5	ND	ND	242.3	$206		out	y
FX 988175	Air	7	11-Feb-98	13-Feb-98	Room	23-Feb-98	107.7	ND	ND	101	$206		out	y
FX 988176	Air	16	11-Feb-98	13-Feb-98	Room	23-Feb-98	130	ND	ND	77.7	$206		out	y
FX 988177	Air	22	11-Feb-98	13-Feb-98	Room	23-Feb-98	13.2	ND	ND	215.6	$206		out	
FX 988178	Air	8	11-Feb-98	13-Feb-98	Room	23-Feb-98	35.7	ND	ND	181.1	$206		out	
FX 988179	Air	1	11-Feb-98	13-Feb-98	Room	23-Feb-98	6.3	ND	ND	117	$206		out	
FX 988180	Air	12	11-Feb-98	13-Feb-98	Room	23-Feb-98	88.4	ND	ND	114	$206		out	y
FX 988181	Air	Blank	11-Feb-98	13-Feb-98	Room	23-Feb-98	ND	ND	ND	ND	$206	Openned and sitting in Greenhouse for approx. 3 weeks	b	
FX 988182	Air	Blank	14-Feb-98	17-Feb-98	Room	23-Feb-98	4.2	3.4	ND	22	$182	(Used for Calibration since 1 Jan 98)	in	
FX 988183	Air	9	14-Feb-98	17-Feb-98	Room	23-Feb-98	14.6	8.6	ND	918.2	$206		in	
FX 988184	Air	21	14-Feb-98	17-Feb-98	Room	23-Feb-98	21.4	11	ND	1508	$206		in	
FX 988185	Air	Blank	14-Feb-98	17-Feb-98	Room	23-Feb-98	ND	ND	ND	ND	$206	**Pump on @ 12:00 11 Feb 98**	in	
FX 988186	Air	17	14-Feb-98	17-Feb-98	Room	23-Feb-98	19.3	8.9	ND	1276.8	$206	**Pump off @ 17:05 14 Feb 98**	in	
FX 988187	Air	10	14-Feb-98	17-Feb-98	Room	25-Feb-98	41.8	ND	ND	960	$206		in	
FX 988188	Air	4	14-Feb-98	17-Feb-98	Room	25-Feb-98	22.7	1.7	ND	532	$206		in	
FX 988189	Air	15	14-Feb-98	17-Feb-98	Room	25-Feb-98	50	3.9	ND	1033	$206	(In Samples)	in	
FX 988190	Air	Blank	14-Feb-98	17-Feb-98	Room	25-Feb-98	ND	ND	ND	ND	$206		in	
FX 988191	Air	6	14-Feb-98	17-Feb-98	Room	25-Feb-98	46.8	3.9	ND	981	$206		in	

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Sample No.	Type of Sample	Chambe No.	Collection Date	Lab Rec'd Date	Temp at Lab	Analysis Date	Results				Cost	Comments	Air In/Out	B-T >10%
							TCE	DCE	VC	CT				
FX 988192	Air	24	14-Feb-98	17-Feb-98	Room	25-Feb-98	21.9	8.3	ND	1394.4	$206		in	
FX 988193	Air	11	14-Feb-98	17-Feb-98	Room	25-Feb-98	26.4	8.6	ND	1433	$206		in	
FX 988194	Air	18	14-Feb-98	17-Feb-98	Room	25-Feb-98	3.7	ND	ND	341	$206		in	
FX 988195	Air	5	14-Feb-98	17-Feb-98	Room	25-Feb-98	24	7.7	ND	1437.4	$206		in	
FX 988196	Air	19	14-Feb-98	17-Feb-98	Room	25-Feb-98	17.9	7	ND	1193	$206		in	
FX 988197	Air	13	14-Feb-98	17-Feb-98	Room	25-Feb-98	15.7	6.4	ND	1157	$206		in	
FX 988198	Air	14	14-Feb-98	17-Feb-98	Room	25-Feb-98	17	7.8	ND	1313	$206		in	
FX 988199	Air	20	14-Feb-98	17-Feb-98	Room	25-Feb-98	15.3	6.7	ND	1213	$206		in	
FX 988200	Air	2	14-Feb-98	17-Feb-98	Room	25-Feb-98	ND	ND	ND	51.5	$206		in	
FX 988201	Air	23	14-Feb-98	17-Feb-98	Room	25-Feb-98	11.7	7	ND	1205	$206		in	
FX 988202	Air	3	14-Feb-98	17-Feb-98	Room	25-Feb-98	13.7	7.2	ND	1347	$206		in	
FX 988203	Air	7	14-Feb-98	17-Feb-98	Room	25-Feb-98	16.7	6.9	ND	1445.1	$206		in	
FX 988204	Air	16	14-Feb-98	17-Feb-98	Room	25-Feb-98	13.5	7.5	ND	1344	$206		in	
FX 988205	Air	22	14-Feb-98	17-Feb-98	Room	25-Feb-98	10.5	5.2	ND	990	$206		in	
FX 988206	Air	8	14-Feb-98	17-Feb-98	Room	25-Feb-98	13.7	6.9	ND	1181	$206		in	
FX 988207	Air	1	14-Feb-98	17-Feb-98	Room	25-Feb-98	17.1	7.7	ND	1373	$206		in	
FX 988208	Air	12	14-Feb-98	17-Feb-98	Room	25-Feb-98	12.6	7.3	ND	1172	$206		in	
FX 988209	Air	Blank	14-Feb-98	17-Feb-98	Room	25-Feb-98	ND	ND	ND	ND	$206		in	
FX 988210	Air	9	14-Feb-98	17-Feb-98	Room	25-Feb-98	378.9	ND	ND	719.5	$206		out	y
FX 988211	Air	21	14-Feb-98	17-Feb-98	Room	25-Feb-98	91	ND	ND	165	$206		out	y
FX 988212	Air	17	14-Feb-98	17-Feb-98	Room	25-Feb-98	180.6	ND	ND	568.2	$206		out	y
FX 988213	Air	10	14-Feb-98	17-Feb-98	Room	25-Feb-98	526.7	ND	ND	847.9	$206		out	y
FX 988214	Air	4	14-Feb-98	17-Feb-98	Room	25-Feb-98	199.8	ND	ND	630	$206		out	y
FX 988215	Air	15	14-Feb-98	17-Feb-98	Room	25-Feb-98	157.2	ND	ND	380.2	$206		out	y
FX 988216	Air	Blank	14-Feb-98	17-Feb-98	Room	25-Feb-98	ND	ND	ND	ND	$206		b	
FX 988217	Air	6	14-Feb-98	17-Feb-98	Room	25-Feb-98	119.4	ND	ND	202.1	$206		out	y
FX 988218	Air	24	14-Feb-98	17-Feb-98	Room	25-Feb-98	26.2	ND	ND	304.2	$206	(Out Samples)	out	y
FX 988219	Air	11	14-Feb-98	17-Feb-98	Room	25-Feb-98	334.4	ND	ND	308.9	$206		out	y
FX 988220	Air	18	14-Feb-98	17-Feb-98	Room	25-Feb-98	183.4	ND	ND	571	$206		out	y
FX 988221	Air	5	14-Feb-98	17-Feb-98	Room	25-Feb-98	110.4	ND	ND	231	$206		out	y
FX 988222	Air	19	14-Feb-98	17-Feb-98	Room	25-Feb-98	ND	ND	ND	262	$206		out	
FX 988223	Air	13	14-Feb-98	17-Feb-98	Room	25-Feb-98	177	ND	ND	241.7	$206		out	y
FX 988224	Air	14	14-Feb-98	17-Feb-98	Room	25-Feb-98	193.7	ND	ND	136.3	$206	**Limits of Detection:**	out	y
FX 988225	Air	20	14-Feb-98	17-Feb-98	Room	25-Feb-98	3	ND	ND	360.5	$206	**TCE: 1.2 ug**	out	
FX 988226	Air	2	14-Feb-98	17-Feb-98	Room	25-Feb-98	105.7	ND	ND	66.5	$206	**DCE: 1.2 ug**	out	y
FX 988227	Air	23	14-Feb-98	17-Feb-98	Room	25-Feb-98	ND	ND	ND	268.5	$206	**VC: 1.7 ug**	out	
FX 988228	Air	3	14-Feb-98	17-Feb-98	Room	25-Feb-98	207.3	ND	ND	50.4	$206	**CT: 6.3 ug**	out	y
FX 988229	Air	7	14-Feb-98	17-Feb-98	Room	25-Feb-98	204.6	ND	ND	217.9	$206		out	y
FX 988230	Air	16	14-Feb-98	17-Feb-98	Room	25-Feb-98	253.8	ND	ND	146.8	$206		out	y

TABLE D-1. (Con't.)

Sample No.	Type of Sample	Chambe No.	Collection Date	Lab Rec'd Date	Temp at Lab	Analysis Date	Results				Cost	Comments	Air In/Out	B-T >10%
							TCE	DCE	VC	CT				
FX 988231	Air	22	14-Feb-98	17-Feb-98	Room	25-Feb-98	2.7	ND	ND	528.6	$206		out	
FX 988232	Air	Blank	14-Feb-98	17-Feb-98	Room	25-Feb-98	ND	ND	ND	ND	$206		b	
FX 988233	Air	8	14-Feb-98	17-Feb-98	Room	25-Feb-98	16.5	ND	ND	308.8	$206		out	
FX 988234	Air	1	14-Feb-98	17-Feb-98	Room	25-Feb-98	159.5	ND	ND	60	$206		out	y
FX 988235	Air	12	14-Feb-98	17-Feb-98	Room	25-Feb-98	144.1	ND	ND	212.2	$206		out	y
GN 988236	Water	Blank	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75	ND = No Detection with detection limit of 5 ug/L		
GN 988237	Water	19	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75			
GN 988238	Water	20	14-Feb-98	17-Feb-98	4 C	18-Feb-98	42.3	ND	ND	ND	$75	Results reported in ug/L		
GN 988239	Water	21	14-Feb-98	17-Feb-98	4 C	18-Feb-98	516.3	ND	ND	ND	$75			
GN 988240	Water	22	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75			
GN 988241	Water	23	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75			
GN 988242	Water	24	14-Feb-98	17-Feb-98	4 C	18-Feb-98	181.2	ND	ND	ND	$75			
GN 988243	Water	Blank	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75			
GN 988244	Water	Blank	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75			
GN 988245	Water	1	14-Feb-98	17-Feb-98	4 C	18-Feb-98	11.5	ND	ND	ND	$75			
GN 988246	Water	2	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75			
GN 988247	Water	3	14-Feb-98	17-Feb-98	4 C	18-Feb-98	179.1	ND	ND	ND	$75			
GN 988248	Water	4	14-Feb-98	17-Feb-98	4 C	18-Feb-98	1250.2	ND	ND	ND	$75			
GN 988249	Water	5	14-Feb-98	17-Feb-98	4 C	18-Feb-98	787.1	ND	ND	ND	$75			
GN 988250	Water	6	14-Feb-98	17-Feb-98	4 C	18-Feb-98	1270.9	ND	ND	ND	$75			
GN 988251	Water	Blank	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75			
GN 988252	Water	7	14-Feb-98	17-Feb-98	4 C	18-Feb-98	1642.9	ND	ND	ND	$75			
GN 988253	Water	8	14-Feb-98	17-Feb-98	4 C	18-Feb-98	297	ND	ND	ND	$75			
GN 988254	Water	9	14-Feb-98	17-Feb-98	4 C	18-Feb-98	963.9	ND	ND	ND	$75			
GN 988255	Water	10	14-Feb-98	17-Feb-98	4 C	18-Feb-98	1508.6	ND	ND	ND	$75			
GN 988256	Water	11	14-Feb-98	17-Feb-98	4 C	18-Feb-98	803.8	ND	ND	ND	$75			
GN 988257	Water	12	14-Feb-98	17-Feb-98	4 C	18-Feb-98	1364.2	ND	ND	ND	$75			
GN 988258	Water	Blank	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75			
GN 988259	Water	13	14-Feb-98	17-Feb-98	4 C	18-Feb-98	978	ND	ND	ND	$75			
GN 988260	Water	14	14-Feb-98	17-Feb-98	4 C	18-Feb-98	1089.8	ND	ND	ND	$75			
GN 988261	Water	15	14-Feb-98	17-Feb-98	4 C	18-Feb-98	1804.9	ND	ND	ND	$75			
GN 988262	Water	16	14-Feb-98	17-Feb-98	4 C	18-Feb-98	1727	ND	ND	ND	$75	EPA Method 624		
GN 988263	Water	17	14-Feb-98	17-Feb-98	4 C	18-Feb-98	924.8	ND	ND	ND	$75	Limit of Detection = 5 ug/L		
GN 988264	Water	18	14-Feb-98	17-Feb-98	4 C	18-Feb-98	1163.7	ND	ND	ND	$75			
GN 988265	Water	Blank	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75			
GS 988266	Soil	Blank	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75	EPA Method SW 8260		
GS 988267	Soil	1	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75	Limit of Detection = 2 ug/kg		
GS 988268	Soil	1	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75	Limit of Quantitation = 10 ug/kg		
GS 988269	Soil	1	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75			

TABLE D-1. (Con't.)

Sample No.	Type of Sample	Chambe No.	Collection Date	Lab Rec'd Date	Temp at Lab	Analysis Date	Results				Cost	Comments
							TCE	DCE	VC	CT		
GS 988270	Soil	2	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75	
GS 988271	Soil	2	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75	
GS 988272	Soil	2	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75	
GS 988273	Soil	3	14-Feb-98	17-Feb-98	4 C	18-Feb-98	18	ND	ND	ND	$75	
GS 988274	Soil	3	14-Feb-98	17-Feb-98	4 C	18-Feb-98	3.6	ND	ND	ND	$75	
GS 988275	Soil	3	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75	
GS 988276	Soil	4	14-Feb-98	17-Feb-98	4 C	18-Feb-98	30.6	ND	ND	ND	$75	
GS 988277	Soil	4	14-Feb-98	17-Feb-98	4 C	18-Feb-98	8	ND	ND	ND	$75	
GS 988278	Soil	4	14-Feb-98	17-Feb-98	4 C	18-Feb-98	81.4	ND	ND	ND	$75	
GS 988279	Soil	5	14-Feb-98	17-Feb-98	4 C	18-Feb-98	31	ND	ND	ND	$75	
GS 988280	Soil	5	14-Feb-98	17-Feb-98	4 C	18-Feb-98	11.9	ND	ND	ND	$75	
GS 988281	Soil	5	14-Feb-98	17-Feb-98	4 C	18-Feb-98	3.6	ND	ND	ND	$75	
GS 988282	Soil	Blank	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75	
GS 988283	Soil	6	14-Feb-98	17-Feb-98	4 C	18-Feb-98	31.5	ND	ND	ND	$75	
GS 988284	Soil	6	14-Feb-98	17-Feb-98	4 C	18-Feb-98	6.5	ND	ND	ND	$75	
GS 988285	Soil	6	14-Feb-98	17-Feb-98	4 C	18-Feb-98	5.4	ND	ND	ND	$75	
GS 988286	Soil	7	14-Feb-98	17-Feb-98	4 C	18-Feb-98	53.1	ND	ND	ND	$75	
GS 988287	Soil	7	14-Feb-98	17-Feb-98	4 C	18-Feb-98	17.6	ND	ND	ND	$75	
GS 988288	Soil	7	14-Feb-98	17-Feb-98	4 C	18-Feb-98	6.1	ND	ND	ND	$75	
GS 988289	Soil	8	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75	
GS 988290	Soil	8	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75	
GS 988291	Soil	8	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75	
GS 988292	Soil	9	14-Feb-98	17-Feb-98	4 C	18-Feb-98	25.5	ND	ND	ND	$75	
GS 988293	Soil	9	14-Feb-98	17-Feb-98	4 C	18-Feb-98	5.1	ND	ND	ND	$75	
GS 988294	Soil	9	14-Feb-98	17-Feb-98	4 C	18-Feb-98	3	ND	ND	ND	$75	
GS 988295	Soil	10	14-Feb-98	17-Feb-98	4 C	18-Feb-98	46.4	ND	ND	ND	$75	
GS 988296	Soil	10	14-Feb-98	17-Feb-98	4 C	18-Feb-98	56.7	ND	ND	ND	$75	
GS 988297	Soil	10	14-Feb-98	17-Feb-98	4 C	18-Feb-98	4.2	ND	ND	ND	$75	
GS 988298	Soil	Blank	14-Feb-98	17-Feb-98	4 C	18-Feb-98	ND	ND	ND	ND	$75	
GS 988299	Soil	11	14-Feb-98	17-Feb-98	4 C	18-Feb-98	30	ND	ND	ND	$75	
GS 988300	Soil	11	14-Feb-98	17-Feb-98	4 C	18-Feb-98	7	ND	ND	ND	$75	
GS 988301	Soil	11	14-Feb-98	17-Feb-98	4 C	18-Feb-98	2.6	ND	ND	ND	$75	
GS 988302	Soil	12	14-Feb-98	17-Feb-98	4 C	18-Feb-98	15	ND	ND	ND	$75	
GS 988303	Soil	12	14-Feb-98	17-Feb-98	4 C	18-Feb-98	9	ND	ND	ND	$75	
GS 988304	Soil	12	14-Feb-98	17-Feb-98	4 C	18-Feb-98	3.7	ND	ND	ND	$75	
GS 988305	Soil	13	14-Feb-98	17-Feb-98	4 C	18-Feb-98	7.2	ND	ND	ND	$75	
GS 988306	Soil	13	14-Feb-98	17-Feb-98	4 C	19-Feb-98	13.2	ND	ND	ND	$75	
GS 988307	Soil	13	14-Feb-98	17-Feb-98	4 C	19-Feb-98	4.1	ND	ND	ND	$75	
GS 988308	Soil	14	14-Feb-98	17-Feb-98	4 C	19-Feb-98	20.1	ND	ND	ND	$75	

TABLE D-1. (Con't.)

Sample No.	Type of Sample	Chambe No.	Collection Date	Lab Rec'd Date	Temp at Lab	Analysis Date	Results				Cost	Comments
							TCE	DCE	VC	CT		
GS 988309	Soil	14	14-Feb-98	17-Feb-98	4 C	19-Feb-98	10.9	ND	ND	ND	$75	
GS 988310	Soil	14	14-Feb-98	17-Feb-98	4 C	19-Feb-98	2.2	ND	ND	ND	$75	
GS 988311	Soil	15	14-Feb-98	17-Feb-98	4 C	19-Feb-98	27.4	ND	ND	ND	$75	
GS 988312	Soil	15	14-Feb-98	17-Feb-98	4 C	19-Feb-98	4	ND	ND	ND	$75	
GS 988313	Soil	15	14-Feb-98	17-Feb-98	4 C	19-Feb-98	3	ND	ND	ND	$75	
GS 988314	Soil	Blank	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988315	Soil	16	14-Feb-98	17-Feb-98	4 C	19-Feb-98	43.3	ND	ND	ND	$75	
GS 988316	Soil	16	14-Feb-98	17-Feb-98	4 C	19-Feb-98	26.8	ND	ND	ND	$75	
GS 988317	Soil	16	14-Feb-98	17-Feb-98	4 C	19-Feb-98	4.1	ND	ND	ND	$75	
GS 988318	Soil	17	14-Feb-98	17-Feb-98	4 C	19-Feb-98	32.6	ND	ND	ND	$75	
GS 988319	Soil	17	14-Feb-98	17-Feb-98	4 C	19-Feb-98	9.6	ND	ND	ND	$75	
GS 988320	Soil	17	14-Feb-98	17-Feb-98	4 C	19-Feb-98	3.5	ND	ND	ND	$75	
GS 988321	Soil	18	14-Feb-98	17-Feb-98	4 C	19-Feb-98	22.7	ND	ND	ND	$75	
GS 988322	Soil	18	14-Feb-98	17-Feb-98	4 C	19-Feb-98	11.3	ND	ND	ND	$75	
GS 988323	Soil	18	14-Feb-98	17-Feb-98	4 C	19-Feb-98	16.4	ND	ND	ND	$75	
GS 988324	Soil	19	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988325	Soil	19	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988326	Soil	19	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988327	Soil	20	14-Feb-98	17-Feb-98	4 C	19-Feb-98	8.1	ND	ND	ND	$75	
GS 988328	Soil	20	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988329	Soil	20	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988330	Soil	Blank	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988331	Soil	21	14-Feb-98	17-Feb-98	4 C	19-Feb-98	8.2	ND	ND	ND	$75	
GS 988332	Soil	21	14-Feb-98	17-Feb-98	4 C	19-Feb-98	9.5	ND	ND	ND	$75	
GS 988333	Soil	21	14-Feb-98	17-Feb-98	4 C	19-Feb-98	10.8	ND	ND	ND	$75	
GS 988334	Soil	22	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988335	Soil	22	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988336	Soil	22	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988337	Soil	23	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988338	Soil	23	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988339	Soil	23	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988340	Soil	24	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988341	Soil	24	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988342	Soil	24	14-Feb-98	17-Feb-98	4 C	19-Feb-98	3.7	ND	ND	ND	$75	
GS 988343	Soil	Blank	14-Feb-98	17-Feb-98	4 C	19-Feb-98	ND	ND	ND	ND	$75	
GS 988344	Soil	Blank	14-Feb-98	17-Feb-98	4 C	19-Feb-98	616700	ND	ND	ND	$75	
GS 988345	Soil	Blank	14-Feb-98	17-Feb-98	4 C	19-Feb-98	31.7	ND	ND	ND	$75	
GV 988349	Veg	1	14-Feb-98	15-Feb-98	Room	19-Feb-98	0					
GV 988350	Veg	2	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					

TABLE D-1. (Con't.)

Sample No.	Type of Sample	Chambe No.	Collection Date	Lab Rec'd Date	Temp at Lab	Analysis Date	Results				Cost	Comments
							TCE	DCE	VC	CT		
GV 988351	Veg	3	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988352	Veg	4	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988353	Veg	5	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988354	Veg	6	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988355	Veg	7	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988356	Veg	11	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988357	Veg	13	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988358	Veg	14	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988359	Veg	15	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988360	Veg	16	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988361	Veg	17	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988362	Veg	18	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988363	Veg	19	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988364	Veg	20	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988365	Veg	21	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988366	Veg	22	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988367	Veg	23	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
GV 988368	Veg	24	14-Feb-98	15-Feb-98	Room	23-Feb-98	0					
FX 988369	Air	Open	14-Mar-98	17-Mar-98	Room	17-Mar-98	39.6			1400.3	$96	
FX 988370	Air	TCE	14-Mar-98	17-Mar-98	Room	17-Mar-98	25.8			648	$96	
FX 988371	Air	Blank	14-Mar-98	17-Mar-98	Room	17-Mar-98	ND			ND	$96	
FX 988372	Air	Open	14-Mar-98	17-Mar-98	Room	17-Mar-98	26.4			975.4	$96	
FX 988373	Air	Open	14-Mar-98	17-Mar-98	Room	17-Mar-98	18.6			735	$96	
FX 988374	Air	Blank	14-Mar-98	17-Mar-98	Room	17-Mar-98	ND			ND	$96	
FX 988375	Air	Open	14-Mar-98	17-Mar-98	Room	17-Mar-98	10.2			449	$96	
FX 988376	Air	Open	14-Mar-98	17-Mar-98	Room	17-Mar-98	21.2			833	$96	
FX 988377	Air	Open	14-Mar-98	17-Mar-98	Room	17-Mar-98	17.1			684	$96	
FX 988378	Air	Blank	14-Mar-98	17-Mar-98	Room	17-Mar-98	ND			ND	$96	

Samples were analyzed for TCE only

Results Reported in micrograms (ug)

Samples were analyzed for TCE & CT only

TABLE D-2.

Review of Air Sampling Data.

This table provides the result of each "out-line" sample, day taken, and percentage of breakthrough.

No.	Day	Front	Back	% BT
1	1			
1	12	559	347	62%
1	26	171	109	64%
1	37	116	71.8	62%
1	40	34.4	25	73%
1	43	114	45.5	40%
2	1			
2	8*	1544	415	27%
2	12	167	109	65%
2	26	78	51.4	66%
2	37	17.3	17.4	101%
2	40	70.5	28.2	40%
2	43	67.1	38.6	58%
3	1			
3	12	289	152	53%
3	26	121	71.6	59%
3	37	187	95.9	51%
3	40	149	74.5	50%
3	43	164	43.3	26%

No.	Day	Front	Back	% BT
7	1			
7	12	383	213	56%
7	26	429	167	39%
7	37	143	44.5	31%
7	40	92.9	14.8	16%
7	43	151	53.6	35%
8	1			
8	12	317	210	66%
8	26	45.7	16.1	35%
8	37	130	24.8	19%
8	40	35.7		0%
8	43	16.5		0%
9	1			
9	12	87.1	29.1	33%
9	26	175	76.8	44%
9	37	288	176	61%
9	40	158	32.9	21%
9	43	301	77.9	26%

No.	Day	Front	Back	% BT
13	12	488	269	55%
13	26	156	99.4	64%
13	37	159	129	81%
13	40	89.4	26.5	30%
13	43	128	50	39%
14	12	252	207	82%
14	26	204	110	54%
14	37	172	88.7	52%
14	40	159	60.1	38%
14	43	143	50.9	36%
15	12	221	110	50%
15	26	176	69.3	39%
15	37	115	66.6	58%
15	40	151	63.2	42%
15	43	108	49.2	46%
16	12	451	203	45%
16	26	165	75.9	46%
16	37	ND	ND	
16	40	99	31	31%
16	43	178	75.8	43%

TABLE D-2. (Con't)

No.	Day	Front	Back	% BT
4	1			
4	12	145	105	72%
4	26	110	43.6	40%
4	37	88.9	63.7	72%
4	40	133	70.8	53%
4	43	134	65.8	49%
5	1			
5	12	195	104	53%
5	26	97.9	47.9	49%
5	37	96.8	76.4	79%
5	40	80.2	14.9	19%
5	43	91.9	18.5	20%
6	1			
6	12	435	251	58%
6	26	171	68.1	40%
6	37	119	57	48%
6	40	155	53.7	35%
6	43	90.6	29.8	33%

No.	Day	Front	Back	% BT
10	12	83.1	17.2	21%
10	26	342	208	61%
10	37	542	337	62%
10	40	209	47.2	23%
10	43	450	76.7	17%
11	12	103	42.6	41%
11	26	288	141	49%
11	37	241	151	63%
11	40	179	47.4	26%
11	43	233	97.4	42%
12	12	97.2	32.6	34%
12	26	138	37.2	27%
12	37	165	86.1	52%
12	40	79.6	8.8	11%
12	43	127	17.1	13%

No.	Day	Front	Back	% BT
17	12	458	250	55%
17	26	256	130	51%
17	37	147	112	76%
17	40	182	57.4	32%
17	43	123	57.6	47%
18	12	188	138	73%
18	26	64.5	38.6	60%
18	37	73.9	61.8	84%
18	40	199	102	51%
18	43	120	63.4	53%

* -- Sample was changed at first sign of water in the line.

APPENDIX E

STATISTICAL ANALYSIS

The SAS System

General Linear Models Procedure

Class Level Information.

Class	Levels	Values
Treatment	3	1, 2, 3

Number of observations in data set = 15

Treatment	Type
1	Alfalfa
2	Soil
3	BG w/TCE

Observations	Value
Y1	TCE Recovered from Air
Y2	TCE Recovered from Water
Y3	TCE Recovered from Soil
Y4	Amount of Water Added

Anova Test

Dependent Variable: Y1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	363560.95	181780.47	1.16	0.3449
Error	12	1872549.63	156045.80		
Corrected Total	14	2236110.58			

R-Square	C.V.	Root MSE	Y1 Mean
0.162586	28.71	395.03	1376

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	2	363560.95	181780.47	1.16	0.3449

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	2	363560.95	181780.47	1.16	0.3449

Dependent Variable: Y2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	116766	58383	1.37	0.2914
Error	12	511719	42643		
Corrected Total	14	628485			

R-Square	C.V.	Root MSE	Y2 Mean
0.185789	35.48	206.50	581.96

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	2	116765.59	58382.80	1.37	0.2914

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	2	116765.59	58382.80	1.37	0.2914

Dependent Variable: Y3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3027.37	1513.68	0.45	0.6507
Error	12	40779.38	3398.28		
Corrected Total	14	43806.75			

R-Square	C.V.	Root MSE	Y3 Mean
0.069107	49.24	58.29	118.39

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	2	3027.37	1513.68	0.45	0.6507

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	2	3027.37	1513.68	0.45	0.6507

Dependent Variable: WATER

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3008050.42	1504025.21	29.99	0.0001
Error	12	601739.58	50144.97		
Corrected Total	14	3609790			

R-Square	C.V.	Root MSE	WATER Mean
0.833303	14.057	223.931	1593

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Treatment	2	3008050.42	1504025.21	29.99	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	2	3008050.42	1504025.21	29.99	0.0001

Least Squares Means

Treatment	Y1 LSMEAN	Y2 LSMEAN	Y3 LSMEAN	WATER LSMEAN
1	1139.93	435.91	122.06	1993.75
2	1542.46	628.34	135.01	965
3	1394.67	640.68	102.1	1849.17

E = Error SS&CP Matrix

	Y1	Y2	Y3	WATER
Y1	1872549.633	-110859.16	98393.03	-322315.54
Y2	-110859.1566	511718.97	89929.35	222712.48
Y3	98393.0329	89929.35	40779.38	25955.63
WATER	-322315.5417	222712.48	25955.63	601739.58

Multivariate Analysis of Variance

Partial Correlation Coefficients from the Error SS&CP Matrix / Prob > |r|

DF = 12	Y1	Y2	Y3	WATER
Y1	1	-0.11325	0.356063	-0.303641
P	0.0001	0.7126	0.2324	0.3132
Y2	-0.11325	1	0.622537	0.401351
P	0.7126	0.0001	0.0231	0.1741
Y3	0.356063	0.622537	1	0.165694
P	0.2324	0.0231	0.0001	0.5885
WATER	-0.303641	0.401351	0.165694	1
P	0.3132	0.1741	0.5885	0.0001

Characteristic Roots and Vectors of: E Inverse * H, where
H = Type III SS&CP Matrix for TRT E = Error SS&CP Matrix

Characteristic Root	Percent	Characteristic Vector V'EV=1			
		Y1	Y2	Y3	WATER
6.68783744	87.41	0.00006884	-0.0008217	0.00037592	0.00143467
0.96306567	12.59	0.00064791	0.0017486	-0.00658245	0.00025165
0	0	0.00062501	-0.00051235	0.00150624	0.00016769
0	0	-0.00012937	0.00056281	0.00341614	0.00009768

Manova Test Criteria and F Approximations for the Hypothesis of no Overall TRT Effect

H = Type III SS&CP Matrix for TRT E = Error SS&CP Matrix

S=2 M=0.5 N=3.5

Statistic	Value	F Num	DF	Den DF	Pr > F
Wilks' Lambda	0.06626146	6.4908	8	18	0.0005
Pillai's Trace	1.3605171	5.3188	8	20	0.0011
Hotelling-Lawley Trace	7.65090311	7.6509	8	16	0.0003
Roy's Greatest Root	6.68783744	16.7196	4	10	0.0002

NOTE: 1. F Statistic for Roy's Greatest Root is an upper bound. 2. F Statistic for Wilks' Lambda is exact.

Dependent Variable: Y1

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	2	363560.95	181780.47	1.16	0.3449
Error	12	1872549.63	156045.80		

Dependent Variable: Y2

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	2	116765.59	58382.80	1.37	0.2914
Error	12	511718.97	42643.25		

Dependent Variable: Y3

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	2	3027.37	1513.68	0.45	0.6507
Error	12	40779.38	3398.28		

Dependent Variable: WATER

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treatment	2	3008050.42	1504025.21	29.99	0.0001
Error	12	601739.58	50144.97		

Scheffe's Test

NOTE: This test controls the type I experimentwise error rate but generally has a higher type II error rate than Tukey's for all pairwise comparisons.

*Comparisons significant at the 0.05 level are indicated by '***'.*

Scheffe's test for variable: Y1

Alpha= 0.05 Confidence= 0.95 df= 12 MSE= 156045.8 Critical Value of F=3.88529

Treatment	Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
2	-3	-519	147.8	814.6
2	-1	-336.1	402.5	1141.2
3	-2	-814.6	-147.8	519
3	-1	-456.1	254.7	965.5
1	-2	-1141.2	-402.5	336.1
1	-3	-965.5	-254.7	456.1

Scheffe's test for variable: Y2

Alpha= 0.05 Confidence= 0.95 df= 12 MSE= 42543.25 Critical Value of F=3.88529

Treatment	Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit
3	-2	-336.2	12.3	360.9
3	-1	-166.8	204.8	576.3
2	-3	-360.9	-12.3	336.2
2	-1	-193.7	192.4	578.6
1	-3	-576.3	-204.8	166.8
1	-2	-578.6	-192.4	193.7

Scheffe's test for variable: Y3

Alpha= 0.05 Confidence= 0.95 df= 12 MSE= 2298.281 Critical Value of F=3.88529

Treatment	Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
2	-1	-96.05	12.96	121.97	
2	-3	-65.49	32.91	131.31	
1	-2	-121.97	-12.96	96.05	
1	-3	-84.94	19.96	124.85	
3	-2	-131.31	-32.91	65.49	
3	-1	-124.85	-19.96	84.94	

Scheffe's test for variable: WATER

Alpha= 0.05 Confidence= 0.95 df= 12 MSE= 50144.97 Critical Value of F=3.88529

Treatment	Comparison	Simultaneous Lower Confidence Limit	Difference Between Means	Simultaneous Upper Confidence Limit	
1	-3	-258.4	144.6	547.5	
1	-2	610	1028.8	1447.5	***
3	-1	-547.5	-144.6	258.4	
3	-2	506.2	884.2	1262.2	***
2	-1	-1447.5	-1028.8	-610	***
2	-3	-1262.2	-884.2	-506.2	***

VITA

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